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THE RELATIONSHIPS OF CLIMATE AND TERRAIN TO MAINTENANCE OF WAY ON THE NORFOLK SOUTHERN RAILROAD BETWEEN NORFOLK, VIRGINIA, AND PORTSMOUTH, OHIO

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Thomas Brock Maertens, Jr.

August 1990

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*

2. REPORT DATE
Jun 90

3. REPORT TYPE AND DATES COVERED
Ph.D. Dissertation

4. TITLE AND SUBTITLE
The Relationships of Climate and Terrain to Maintenance of Way on the Norfolk Southern Railroad Between Norfolk, Virginia, and Portsmouth, Ohio

5. FUNDING NUMBERS
N/A

6. AUTHOR(S)
Thomas Brock Maertens, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
N/A

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Department of Geography and Environmental Engineering
United States Military Academy, West Point, NY

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
N/A

11. SUPPLEMENTARY NOTES
Prepared in conjunction with the award of the Doctor of Philosophy degree in geography at the University of Tennessee--Knoxville.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Available to the public; send copy to NTIS.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)* The relationships of climate and terrain to maintenance of way on the Norfolk Southern railroad between Norfolk, Va., and Portsmouth, Ohio, are considered as environmental factors affecting maintenance of way costs. An analysis of the distribution of maintenance of way problems is conducted using 54 Railroad Study Units and 10 climate and terrain variables to develop Railroad Maintainability Factors (RMF's). The RMF's are classified into Railroad Maintainability Zones (RMZ's) and projected along the 540-mile study route, ranging from a Very Low RMZ in the Gulf Atlantic Coastal Flats in Va. to a Very High RMZ in the upper reaches of the Tug Fork River Basin in W.Va. The relationships of climate and terrain to maintenance of way as manifested in the RMZ's can assist transportation planners in developing new routes or relocating existing routes to reduce long-term maintenance of way costs and to improve system efficiency. Extensions of this methodology to other modes of ground transportation and to other regions would enhance the geographical understanding of the relationships between land-surface systems and ground transportation networks. Applications to military logistics contingency planning are also presented.

14. SUBJECT TERMS railroads, maintenance, maintenance of way, climate and terrain, environmental factors, transportation location analysis, transportation geography

15. NUMBER OF PAGES
~~250~~ 228

16. PRICE CODE
N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

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To the Men Who Work on the Railroads

ACKNOWLEDGMENTS

I am grateful for the assistance and guidance of Professor Carol P. Harden for directing this research project. I am deeply indebted to Professor Emeritus Edwin H. Hammond for his advice and criticism during the organization and development of this study. It was his suggestion that I investigate further my master's work, involving physical geography and transportation. I also appreciate the critical suggestions and encouragement offered by Professors John B. Rehder and Edwin P. Patton.

I greatly appreciate the cooperation and assistance of the Norfolk Southern Corporation, particularly the offices of the Norfolk Southern Railroad Division Engineers in Roanoke, Virginia, and Bluefield, West Virginia. Mr. P. R. Rudder, Vice President--Engineering, and Mr. H. L. Rose, Assistant Vice President--Maintenance, provided the initial corporate support from Norfolk Southern. I am especially grateful to Assistant Division Engineers J. A. McCracken, Virginia Division, and R. L. Meadows, Pocahontas Division, for their technical advice and helpful suggestions provided during many hours of conversation and track patrolling. Many other maintenance-of-way personnel that I encountered during my time with the Norfolk Southern Railroad were also very helpful in providing insight into railroad maintenance operations.

The Special Collections Department of the Virginia Polytechnic Institute and State University Libraries provided access to their railroad collections and photographs. I am grateful for their assistance.

I would like to thank Mr. Will Fontanez, manager of the University of Tennessee Cartographic Services Lab, and his assistant, Mr. James Lemons, for their excellent support.

I also wish to thank both COL Gerald E. Galloway, Head of the Department of Geography and Environmental Engineering at the United States Military Academy, and the Department of Geography at the University of Tennessee, Knoxville, for granting me the opportunity to further my graduate education.

Finally, I wish to thank my wife, Karen, for her understanding and encouragement during the research and preparation of this project. For her dedication in typing the numerous drafts and final copy of this dissertation, I am forever grateful.

ABSTRACT

The relationships of climate and terrain to maintenance of way on the Norfolk Southern railroad between Norfolk, Virginia, and Portsmouth, Ohio, are considered as environmental factors affecting maintenance-of-way costs for the railroad. A detailed analysis of the distribution of actual maintenance-of-way problems along the route is conducted, using 54 Railroad Study Units and 10 climate and terrain variables (local relief, side slopes, sinuosity ratio, total track curvature, freeze/thaw cycles, flood and landslide potentials, annual number of days with precipitation greater than 0.1 inch, extent of cut and fill, and an engineering soil rating), to develop Railroad Maintenance Factors (RMF's). From these RMF's, Railroad Maintenance Zones (RMZ's) can be identified along the 540 miles of the study route. The maintenance zones range from a Very Low RMZ on the Gulf Atlantic Coastal Flats in Virginia to a Very High RMZ in the upper reaches of the Tug Fork River Basin in West Virginia. The relationships of climate and terrain to maintenance of way as manifested in the RMZ's can assist transportation planners in developing new routes or relocating existing routes to reduce long-term maintenance costs and to improve system efficiency. Extensions of the methods used in this study to other modes of ground transportation and to other regions would enhance the geographical understanding of the relationships between

land-surface systems and ground transportation networks. Military applications of the study to military logistics contingency planning are also presented.

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CHAPTER I

INTRODUCTION

Geographers have long recognized that transportation is a valuable aspect of spatial relationships and, as such, it is basic to the study of geography. Railroads, a major mode of transportation, form an integral part of the cultural landscape as man, recognizing the need for transport between centers of population, has modified the physical landscape to accommodate the necessary rail networks, stations, and yards. While railroads are certainly phenomena of prime geographical interest, it is also true that the understanding of the inherent geographical relationships between the land-surface system and railroads is less than satisfactory. The geometric precision of a railroad track curving along the contours of the landscape represents the superposition of a uniform, static network on a varied and dynamic land-surface system. In this dissertation, climate and terrain will be considered as dynamic environmental factors affecting railroad networks. Specifically, this dissertation proposes to describe and analyze the relationships of climate and terrain to maintenance of way on the Norfolk Southern railroad between Norfolk, Virginia, and Portsmouth, Ohio.

Statement of the Problem

Maintenance of way on today's rail lines is vastly improved in comparison with the conditions prevalent on many rail lines in the late 1960's and through part of the 1970's. Railroad management has learned that, in order to succeed in the railroad business, one must have dependable trackage. As a result of railroad deregulation (Staggers Rail Act of 1980), railroad companies must maintain high quality trackage while providing an adequate return for investors and maintaining an adequate market share for the railroad industry.[1] Railroads, unlike trucking and water transportation, own their rights of way, which means that railroads must operate and maintain the tracks and roadbed over which their trains operate.

Maintenance of way[2] has always been an expensive part of the railroad industry. For example, in 1988, the 14 Class I freight railroads in the United States spent $4,397,528--approximately 17.7% of their total operating expenses--on maintenance of way and structures.[3]

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[1]George H. Way, "Introduction," in *Transportation Research Record 1042* (Washington, D.C.: National Research Council, 1985), 1.

[2]Hereafter, unless otherwise noted for clarity, the term "maintenance" will be used to mean maintenance of way.

[3]Association of American Railroads, *Railroad Facts* (Washington, D.C.: Association of American Railroads, 1989), 15. Class I railroads are defined annually by the Interstate Commerce Commission based on the annual operating revenues of a railroad. In 1988, the threshold for the 14

The issue of railroad safety, in terms of accidents and derailments, especially of hazardous materials cargo, has been linked to maintenance conditions on today's railroads.[4] However, statistics indicate that railroad accidents and fatalities have recently decreased. In 1973, 9,698 train accidents occurred, resulting in 1,916 fatalities. By comparison, in 1983, only 3,731 accidents occurred, resulting in 1,045 fatalities.[5] Railroads in the United States transport annually more than one million carloads (80 million tons), or approximately 70%, of all hazardous materials, excluding petroleum, in this country; nevertheless, fewer than 10% of hazardous materials transportation accidents are on the railroads.[6] Certainly, maintenance of way is an important factor in maintaining an acceptable level of railroad safety.

Conditions of track also affect the speed at which trains can operate. Less than optimum track conditions awaiting required maintenance result in the issuance of temporary "slow orders," in which railroad speeds are

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Class I railroads was $92 million. The Norfolk Southern is a Class I railroad.

[4] Andrew Schneider and Lee Bowman, "Nation's Passengers, Freight Ride Crumbling Rail System," *Knoxville News-Sentinel*, 28 September 1988, p. A6.

[5] Department of Transportation, *National Transportation Statistics Annual Report* (Washington, D.C.: Government Printing Office, 1985), 38.

[6] Frederick J. Stephenson, *Transportation USA* (Reading, Mass.: Addison-Wesley Publishing Co., 1987), 167.

restricted over certain sections of track, resulting in longer transit times.[7] Stephenson cites an actual movement of a rail car from Harrisburg, Pennsylvania, to Fresno, California; a trip which took 225 hours (nine days, nine hours) to cover the 3,615 miles. Exclusive of the 87 hours of enroute delays, the road speed along the various rail lines averaged only 26 mph. This is an important economic issue in light of the growth of the trucking industry, a mode of transportation that even over long hauls is usually faster than the railroads. Railroads must strive for greater train speeds to improve their marketability and their productivity.[8] Smoother track also reduces loss and damage claims, especially for vibration-sensitive cargo.

Study and analysis of the geography of railroad maintenance problems should suggest new avenues for cost reduction and system efficiency. Difficulties of maintenance along certain sections of railroads often cannot be fully explained by the company. Close examination of these maintenance problem areas could lead to capital investment in a new right of way that actually would save money in the long term, through the by-passing of a particularly difficult maintenance area. For example, a slight shift in a side-slope location can decrease the

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[7] Other speed restrictions are imposed by the Federal Railroad Administration based on the class of track, degree of curvature, and associated superelevation.

[8] Stephenson, *Transportation USA*, 151-153.

chances of future slides or embankment failures. Relocation of a route segment may bring the track onto more stable subsoil or away from an area of naturally poor drainage.[9] Railroads today are living with roadbeds built in earlier days without the benefit of geotechnical analysis and modern surveying, construction methods, and equipment.

A problem also exists today because of a lack of systematic geotechnical analyses of railroad maintenance problems. Part of the problem is simply staffing. The Norfolk Southern railroad, for example, maintains a geotechnical services office with one geologist and a civil engineer to monitor 30,000 miles of track. Their expertise is usually focused on solving major problems as they arise within the system.[10]

In this dissertation, maintenance problems related to climate and terrain are considered as an aspect of the total maintenance costs for railroads. If the effects of these environmental components can be effectively described and analyzed from a geographical perspective, better planning for railroad location, design, and operation should reduce long-term maintenance costs and improve the overall condition of the nation's railroads. Up to now little

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[9]William W. Hay, *Railroad Engineering* (New York: John Wiley & Sons, 1982), 220.

[10]J. R. Zimmerman, Engineer of Geotechnical Services, Norfolk Southern Corporation, interview by author, 8 June 1989, Atlanta, Ga.

research has focused on the geographical aspects of railroad maintenance of way.

Literature Review

Few geographical studies have even considered the spatial relationships of railroad operations. O'Dell and Richards (1971) discussed geographical factors in light of their influence on the construction and operation of railways throughout the world. Emphasis was placed, however, on railroads in Britain and North America, the former because it was the land in which railways evolved and the latter because it was the first continent to be effectively developed as a result of railway construction.[11] Ayres (1968), a Syracuse University graduate student working under Dr. Edwin Hammond, investigated the geography of maintenance costs on a division of the Denver and Rio Grande Western Railroad in Colorado.[12] He suggested relationships between railroad operating and maintenance costs and terrain. Ayres (1969) also analyzed the relationship of railroad operating costs to terrain in the Middle Atlantic

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[11]Andrew C. O'Dell and Peter S. Richards, *Railways and Geography* (London: Hutchinson's University Library, 1971), 42-77, 139-149.

[12]Steven Edward Ayres, "An Investigation of the Geography of Maintenance Costs on the Denver and Rio Grande Western Railroad" (paper submitted for graduate seminar in geography, Syracuse University, 1968), 1-14.

United States.[13] Ayres' contribution was significant because of his development of an environmental component of railroad operating and maintenance costs. Lalor (1950) considered the impact of physiography on railroad patterns in New England.[14] Through an analysis of seven New England railroads, he focused on the adaptations of railroad technology to the land surface and on the significance of the railroad pattern to New England's economic development. Grey (1963) presented a landform evaluation methodology to investigate the Union Pacific Railroad's selection of a route over the eastern Rocky Mountains.[15] His ideas on land-surface properties, such as patterns, profiles, and dimensions, were useful in this study. Ullman (1949) addressed the relationship of railroads to topography and production in the United States.[16] Meinig (1962) has published a comparative historical geography of two rail systems and concluded that the necessarily intimate relationship of railroad lines to terrain makes it

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[13]Steven Edward Ayres, "Measuring the Difficulty of Terrain for Railroad Operation: Northeastern United States" (M.A. thesis, Syracuse University, 1969), 50-57, 120-123.

[14]Pierce C. Lalor, "The Effect of Physiography on the Railroad Pattern of New England" (M.S. thesis, Clark University, 1950), 48-68.

[15]Alan Hopwood Grey, "A Railroad Across the Mountains: Choosing the Route of the Union Pacific Over the Eastern Rockies" (Ph.D. diss., University of Wisconsin, 1963), 35, 142-178.

[16]Edward L. Ullman, "The Railroad Pattern of the United States," *Geographical Review* 39 (April 1949): 242-256.

insidiously easy to infer that the particular route selected was inevitable. He also stated that railroad strategists are basically practicing geographers who consciously think in spatial terms and conscientiously grapple with regional qualities, variations, and potentialities.[17] Quillen (1969) presented an interesting historical analysis of the now defunct Tennessee Central Railway focusing on economic impacts.[18] Wallace (1956) focused on economic activity and population rather than physical geography.[19] Wallace (1963) provided a classification of railroads in the United States according to their freight traffic characteristics.[20] Maertens (1980) investigated the relationship of highway maintenance costs to terrain and climate on the 450-mile segment of Interstate 40 in Tennessee.[21] While generalized relationships between maintenance costs and environmental

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[17]D. W. Meinig, "A Comparative Historical Geography of Two Railnets: Columbia Basin and South Australia," *Annals of the Association of American Geographers* 52 (December 1962): 394-413.

[18]Dennis E. Quillen, "A Geographic Study of the Tennessee Central Railway: An East-West Transport Route Across the Cumberland Plateau of Tennessee" (M.S. thesis, University of Tennessee, 1969), 34-62, 72-75.

[19]William H. Wallace, "A Geography of the New Zealand Government Railways" (Ph.D. diss., University of Wisconsin, 1956).

[20]William H. Wallace, "Freight Traffic Functions of Anglo-American Railroads," *Annals of the Association of American Geographers* 53 (September 1963): 312-331.

[21]Thomas B. Maertens, Jr. "The Relationship of Maintenance Costs to Terrain and Climate on Interstate 40 in Tennessee" (M.S. thesis, University of Tennessee, 1980).

factors were difficult to establish on a statewide basis, Maertens' detailed analysis of specific high-cost segments of Interstate 40 suggested clear relationships between microenvironmental factors and costs. Significant published studies by geographers of the relationship between environmental factors and the maintenance costs of railroads do not exist.

Transportation literature obtained from the National Research Council's Transportation Research Board includes several technical studies on frost protection, roadbed ballast and subgrade, drainage, weed control, and track maintenance techniques, among others. Professional railroad industry journals, such as *Railway Age*, *Progressive Railroading*, and *Modern Railroads*, contain technical information on maintenance of way. Texts in civil, railroad, and transportation engineering, while inherently technical, supply background information on railroad design, construction, and maintenance. *The Track Cyclopedia* provides valuable information on state-of-the-art practices in the design, construction, and maintenance of track.[22] The Norfolk Southern railroad has provided maps, track charts and standards, and maintenance procedure manuals. U.S. Army technical manuals from the Army's Transportation School cover such subjects as railroad construction, unit

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[22]H. C. Archdeacon, ed., *The Track Cyclopedia* (Omaha, Nebr.: Simmons-Boardman Books, Inc., 1985).

rail operations, and maintenance of way. Manuals from the Army's Engineer School contain information on soils engineering, drainage, and terrain analysis. Huddleston (1989) provides an historical background to the development of the railroads through the Appalachians.[23] Lambie (1954) details the emergence of the Norfolk and Western[24] as a major coal carrier as well as the development of the famous Pocahontas coal fields in western Virginia and southern West Virginia.[25]

Purpose of the Study

The primary purpose of this study is to describe and explain the relationships of climate and terrain to maintenance of way on the Norfolk Southern railroad between Norfolk, Virginia, and Portsmouth, Ohio. As noted, although maintenance of way is a critical element in the operation of the nation's railroads, the relationship of maintenance to climate and terrain has not been investigated by geographers or transportation researchers. This study will enter that area of research deficiency and endeavor to contribute to

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[23] Eugene L. Huddleston, *Appalachian Crossing: The Pocahontas Roads* (Sterling, Va.: TLC Publishing, 1989), 2-6, 29-65.

[24] On 25 March 1982, the Norfolk and Western Railway merged with the Southern Railway System to form the Norfolk Southern Corporation.

[25] Joseph T. Lambie, *From Mine to Market: The History of Coal Transportation on the Norfolk and Western Railway* (New York: New York University Press, 1954), 26-153.

the understanding of the spatial implications of environmental factors on maintenance of way along a major transportation line in the United States.

CHAPTER II

THE STUDY ROUTE: THE NORFOLK SOUTHERN RAILROAD BETWEEN NORFOLK AND PORTSMOUTH

Selection of the Route

In selecting a route for study, the goal was to find a main line route that offered the greatest diversity in operating environments with a minimum of variability in traffic and tonnage. Because of the extensiveness of their networks and their relatively high standards of maintenance, only linehaul, Class I railroads were considered. Railroad systems west of the Mississippi River were not considered because of the constraints of logistics and time. Selection was limited eventually to a single railroad company in order to facilitate access to proprietary data, to ensure standardization of maintenance policies and procedures, and to enhance cooperation. With extensive networks throughout the East, the CSX Corporation located in Jacksonville, the Norfolk Southern Corporation headquartered in Norfolk, and CONRAIL located in Philadelphia were contacted for assistance in this research effort. Obtaining the full cooperation of a railroad company was essential to the success of the project. After careful consideration and discussions with various railroad company officials, the Norfolk Southern railroad was selected as the network for study. Mr. Paul R. Rudder, Executive Vice President for Engineering at the Norfolk Southern headquarters in Norfolk, provided the corporate approval to support the research. Mr. Hubert L. Rose, Assistant Vice President for Maintenance of Way at the Atlanta office of Norfolk Southern, coordinated the author's work with the railroad and provided technical guidance. Given the selection of a rail network, the next goal was to select a particular segment of the Norfolk Southern system for study (see Figure 1).

Since the Norfolk Southern system is the result of the 1982 merger of the Southern and the Norfolk and Western railways, Mr. Rose recommended that the selected route lie within the original structure of either the Southern or the Norfolk and Western. This would ensure internal standardization of maintenance practices and procedures. Rose also suggested that in order to deal with the impact of the weight, speed, and frequency of trains on the rails and roadway, important non-environmental factors, a route with relatively constant tonnage should be selected. He also noted that the routes with the highest traffic density and tonnage received the most attention in the maintenance effort.[26] After an examination of the Norfolk Southern system traffic density maps and the associated topographic maps, a former Norfolk and Western main line route was

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[26]Hubert L. Rose, Assistant Vice President--Maintenance of Way and Structures, Norfolk Southern Corporation, interview by author, 6 June 1989, Atlanta, Ga.

Figure 1. System Map of the Norfolk Southern Railway.

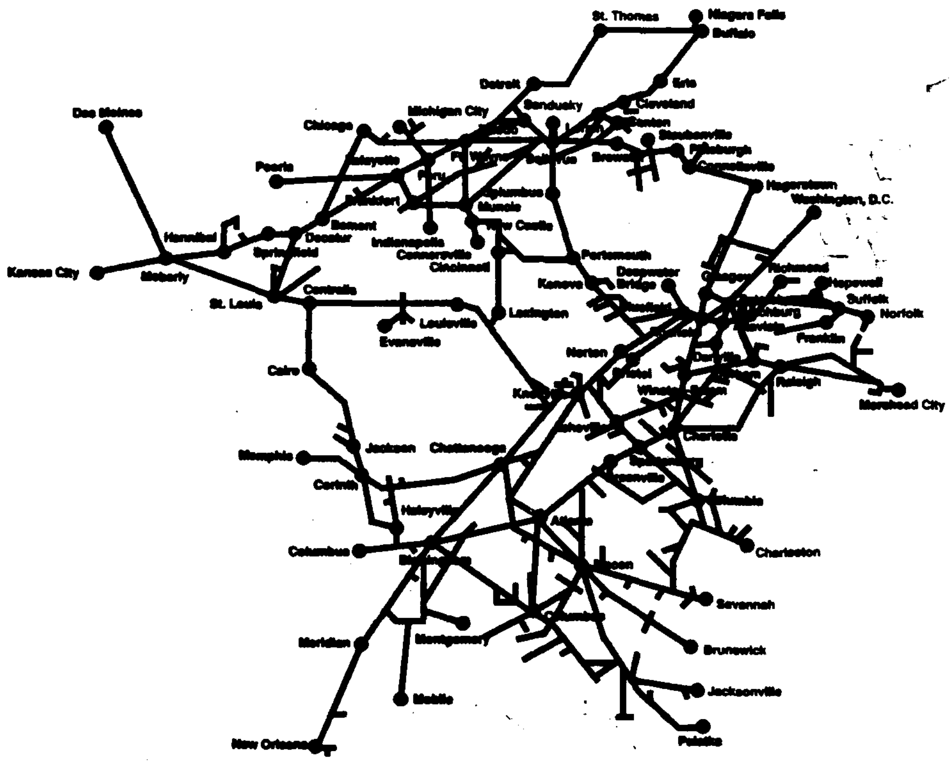
Map of the Norfolk Southern system covering 29,622 miles of track operated over 17,006 miles of road in 20 states.

Scale: 1:16,853,760.

Source: Norfolk Southern Corporation.

SYSTEM MAP OF THE NORFOLK SOUTHERN RAILWAY

266 Miles to the Inch



selected: that between Norfolk, Virginia, and Portsmouth, Ohio (see Figure 2). A portion of this route between Abilene (eight miles east of Cullen) and Narrows, Virginia, had belonged to the former Virginian Railway, which was purchased by the Norfolk and Western in 1959.

History

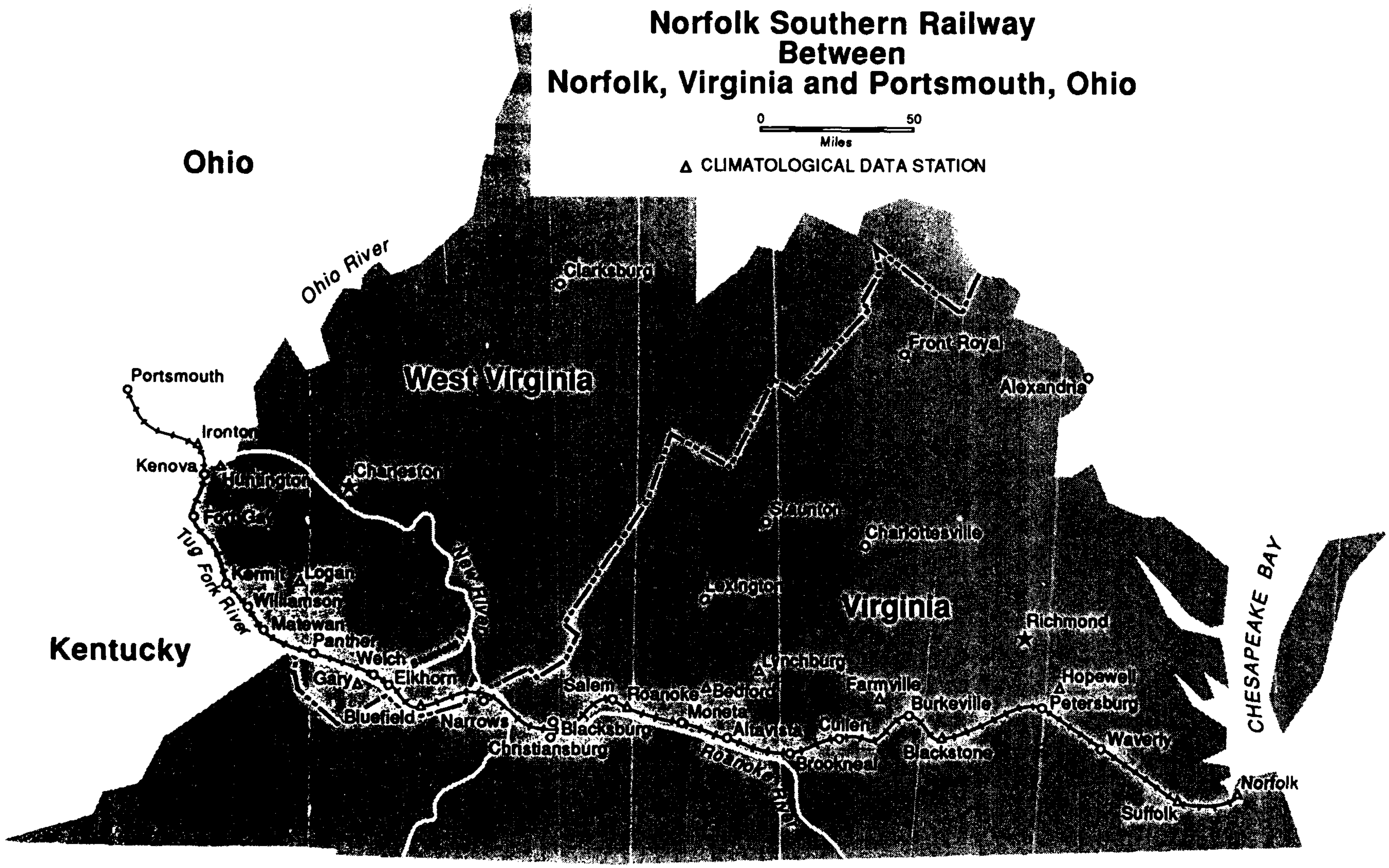
The history of the study route began in the late eighteenth century as pioneer surveyors established three potential transportation routes from Virginia through the Appalachians to the Ohio River: (1) up the North Branch of the Potomac River into the Little Youghiogheny Valley; (2) from the Jackson River (headwaters of the James River) up Dunlap's Creek to Howard's Creek then the Greenbrier, New, and Kanawha rivers; and (3) up the Roanoke River, over the divide from the Roanoke Valley to the New River, and then to the Holston or the Kanawha. In 1825, Claudius Crozet, the Principal Engineer for the Virginia Board of Public Works, surveyed "practicable" canal and rail routes to the west and favored the route from the Roanoke to the New River. Nearly half a century later, the Norfolk and Western, and later the Virginian Railway, would construct rail lines along the Roanoke and New rivers but would leave the New River Valley to follow the East River, a tributary on the eastern edge of the Appalachian Plateau, to the rich Flat Top coal fields. Eventually, the Norfolk and Western would reach the Ohio

Figure 2. Norfolk Southern Railway Between Norfolk, Va., and Portsmouth, Ohio.

The map shows the horizontal alignment of the study route and identifies places along the route.

Scale: 1:3,168,000.

Norfolk Southern Railway
Between
Norfolk, Virginia and Portsmouth, Ohio



River but only over a circuitous and difficult route through the narrow, steep valleys of the Appalachian Plateau.[27]

The Norfolk and Western Railway emerged in 1881 as a result of the foreclosure sale of the financially unsuccessful Atlantic, Mississippi, and Ohio Railroad, which had been formed in 1870 from the consolidation of the Norfolk and Petersburg, the Southside (Petersburg to Lynchburg), and the Virginia and Tennessee (Lynchburg to Bristol) railroads. The Atlantic, Mississippi, and Ohio Railroad had depended on the products of an agrarian South, such as cotton, lumber, tobacco, grains, and cattle, for the majority of its revenue. However, in 1881, a civil engineer and President of the Shenandoah Valley Railroad (owned by the Norfolk and Western), Frederick J. Kimball, discovered a major outcrop of coal in Tazewell County, Virginia (at a place called Abbs Valley, now Pocahontas), and changed the future of the Norfolk and Western Railway. This excellent, 12-foot outcropping known as the Pocahontas Number Three Seam became the immediate economic objective of the Norfolk and Western Railway.[28]

To facilitate the transportation of coal from the Flat Top region, Kimball first connected the Shenandoah Valley Railroad, originating in Hagerstown, Maryland, to the Norfolk and Western Railway at a place known as Big Lick,

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[27]Huddleston, *Appalachian Crossing*, 3-4.

[28]Lambie, *From Mine to Market*, 29-30.

Virginia, on the Roanoke River. Interestingly, on 27 June 1881, the citizens of Big Lick, in appreciation of Kimball's efforts to make Big Lick an important railroad hub, voted to change the name of the town to "Kimball." But, Kimball, modest by nature, declined the offer and the second place name, "Roanoke," was selected.[29] Second, Kimball persuaded the Norfolk and Western board of directors to construct a branch line, the New River Extension, from Radford, Virginia, to Abbs Valley. This line followed the south bank of the New River, ascended the East River at Glen Lyn, Virginia, to the Bluestone River Valley (later the city of Bluefield, West Virginia), and entered the Flat Top area at Abbs Valley. The first coal car was loaded on 12 March 1883.[30]

Kimball became the President of the Norfolk and Western in 1883. He recognized that in order to open up the lucrative coal beds along West Virginia's borders with southwest Virginia and Kentucky, a rail line to the Ohio River from Abbs Valley was necessary. In 1886, construction began on the first Elkhorn Tunnel through Flat Top Mountain, a single-track tunnel of 3,014 feet. The route selected for the Ohio Extension, as it was to be called, passed through the Elkhorn Tunnel, followed Elkhorn Creek to its junction

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[29] Ibid., 15-16.

[30] O. Winston Link, *Steel, Steam and Stars* (New York: Abrams Publishing Co., 1987), 28.

with the Tug Fork of the Big Sandy River (now Welch, West Virginia), and then continued along the Tug Fork to the junction of Pigeon Creek at Naugatuck, located five miles southeast of Kermit. Here, the route followed Pigeon Creek and Laurel Fork to Twelve Pole Creek (through the Dingess Tunnel) and joined the Ohio River just east of Kenova. The total distance from Elkhorn Tunnel to Kenova was 190 miles. In June 1890, 15 contractors and 5,000 men began work from both ends on the Ohio Extension through the wilderness of West Virginia. Work also began on a five-span, 3,886-foot bridge over the Ohio River and on an approach viaduct at Kenova to connect the Norfolk and Western with the Scioto Valley and New England Railroad. This was a short line of 130 miles that connected Ironton, Ohio, to Columbus through Portsmouth. On the Ohio Extension, frequent bridging of the streams was necessary to avoid excessive curvature; for example: (1) the Tug Fork was crossed 10 times; (2) Elkhorn Creek, 13 times; (3) Laurel Fork, four times; and (4) Twelve Pole Creek, 34 times. The construction of eight tunnels was also required. After considerable engineering difficulty, the two segments were linked on 22 September 1892 near Hatfield, West Virginia. Unfortunately, the Twelve Pole Creek segment proved to be completely unsatisfactory because of competition from the Chesapeake and Ohio Railroad, unfavorable track gradients, and excessive distance. Therefore, a new rail line was constructed in 1902 from

Naugatuck, at the mouth of Pigeon Creek, along the Tug Fork and Big Sandy rivers to Kenova on the Ohio River. With the completion of the Ohio Extension, the Norfolk and Western Railway had a main line running 560 miles from Norfolk to Portsmouth through Petersburg, Roanoke, Bluefield, and Kenova.[31]

A portion of the route in this study was surveyed and constructed prior to 1959 by the Virginian Railway. Specifically, the present-day Norfolk Southern track between the New River bridge at Narrows and the rail connection at Abilene, Virginia (175 miles), was originally part of the Virginian Railway System.

The Virginian Railway, unlike the Norfolk and Western, was constructed eastward from the West Virginia coal fields in the Guyandotte River Valley to its east coast terminus at Sewalls Point in Norfolk. Financier Henry Huttleston Rogers, a Standard Oil magnate, constructed the Virginian Railway between 1905 and 1908 with 40 million dollars of his own assets. The route of the Virginian Railway paralleled the route of the Norfolk and Western along the East River in West Virginia, along the New River (the Virginian on the north or east bank and the Norfolk and Western on the south or west bank), over the single divide separating the New River from the Roanoke Basin, and into the city of Roanoke. East of Roanoke, the Virginian Railway followed the Roanoke

[31] Lambie, *From Mine to Market*, 120-125.

River through a water gap in the Blue Ridge then southeast across the Virginia Piedmont, while the Norfolk and Western line passed through a wind gap in the Blue Ridge northeast of Roanoke then traveled to Lynchburg and southeast across the Piedmont. Because the Virginian Railway was constructed about 28 years later than the roughly parallel Norfolk and Western, more advanced engineering techniques permitted cuts and fills of greater magnitude and improved construction of bridges and tunnels. The result was an eastbound line that encountered only one adverse grade of 0.60% at Blacksburg for nine miles and no grades greater than 0.20% for the remaining distance to Norfolk.[32] Hence the newer line was utilized for loaded coal trains when the companies merged.

Overview of Terrain

In order to understand better the ensuing discussion of the terrain along the study area, a brief mention of the general location of the physiographic divisions, using satellite imagery (see Figures 3, 4, 5, and 6) as a reference, follows.[33] The Coastal Plain of Virginia, or Tidewater, extends westward to the Fall Line, or to Petersburg, as seen in Figure 3. It is divided into peninsulas by four principal rivers: the Potomac, the

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[32]Huddleston, *Appalachian Crossing*, 4.

[33]Nevin M. Fenneman, *Physiography of Eastern United States* (New York: McGraw-Hill Book Company, Inc., 1938), 8-304.

Figure 3. Landsat I Image of the Study Area.

A mosaic of Land Satellite (Landsat) imagery showing the terrain of the entire study area. The eastern border includes portions of the Chesapeake Bay while the western border includes Portsmouth and the Ohio River. Because of the small scale of the satellite imagery, the trace of the rail line on Figures 3, 4, 5, and 6 only approximates the actual alignment.

Scale: 1:2,816,000.

Source: Department of Geography, University of Tennessee.

Figure 4. Landsat Band 7 Image of the Study Area, Eastern Region.

Band 7 Land Satellite (Landsat) image of the Ridge and Valley, Blue Ridge, and western Piedmont.

Scale: 1:1,267,000.

Source: Department of Geography, University of Tennessee.

Figure 5. Landsat Band 7 Image of the Study Area, Central Region.

Band 7 Landsat image of the Blue Ridge, Ridge and Valley, and Appalachian Plateau.

Scale: 1:1,267,000.

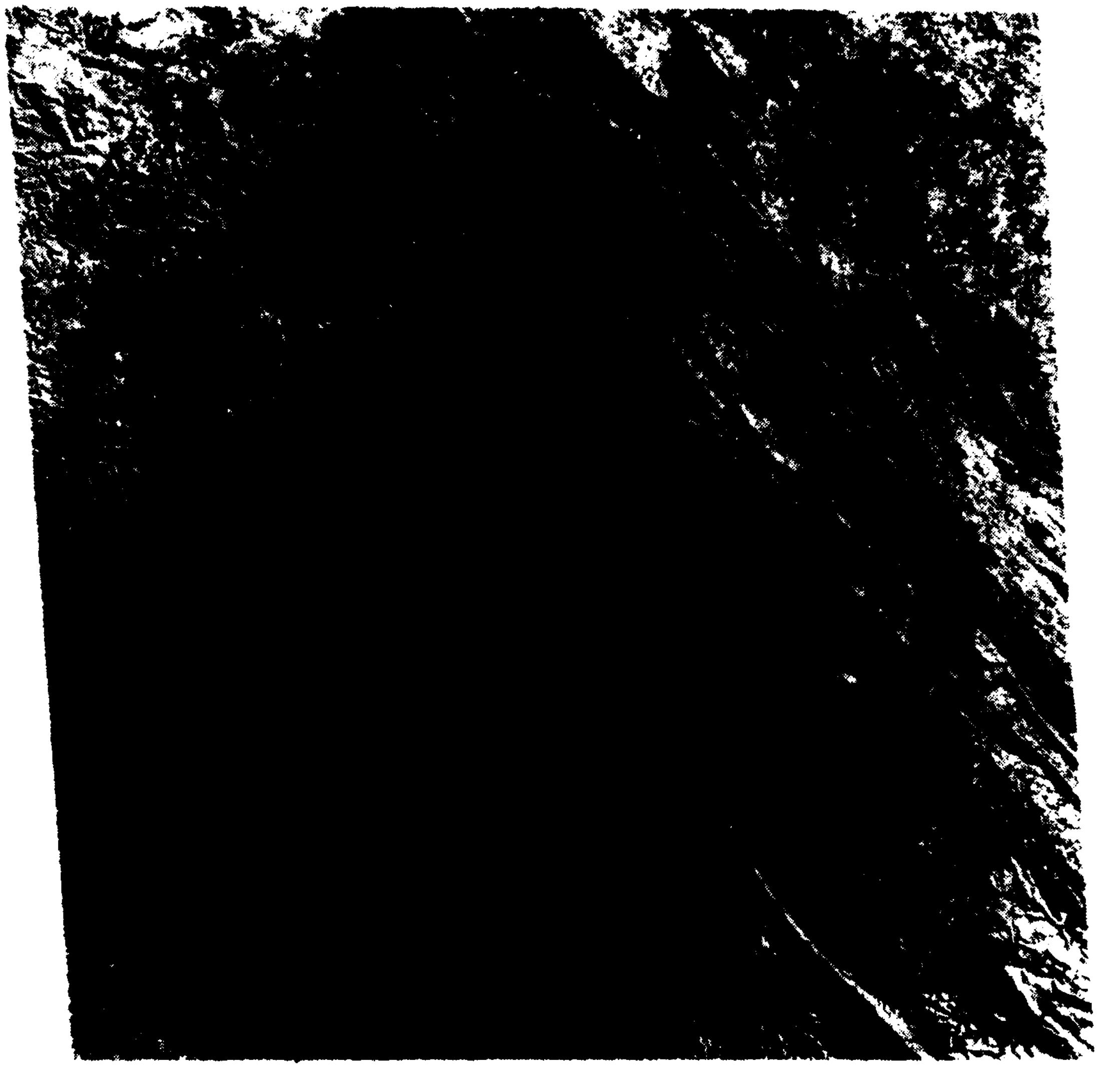
Source: Department of Geography, University of Tennessee.

Figure 6. Landsat Band 7 Image of the Study Area, Western Region.

Band 7 Landsat image of the Ridge and Valley and the Appalachian Plateau.

Scale: 1:1,267,000.

Source: Department of Geography, University of Tennessee.



Rappahannock, the York, and the James. The Piedmont physiographic province is more then 200 miles wide in southern Virginia but narrows to the north. On the imagery, the Piedmont is the area extending from Petersburg to a northeast to southwest line through the northwest tip of Smith Mountain Lake. West of the Piedmont, the narrow Blue Ridge province extends to a northeast to southwest line through Roanoke, as seen in Figure 3, page 24, and Figure 4, page 26. The Ridge and Valley physiographic province continues westward to a northeast to southwest line through Bluefield. The linear ridges and valleys are clearly evident in Figure 5. As best seen in Figures 5 and 6, the remaining area west of the Ridge and Valley is the Appalachian Plateau, with its dendritic drainage patterns, rounded hills and low mountains, steep slopes, and winding valleys. The New River, which drains into the Ohio River, is best seen in Figures 5 and 6. The Roanoke River is most evident in Figure 4, page 26, and the Big Sandy River is seen at its confluence with the Ohio in the upper left corner of Figure 3, page 24. It is difficult to discern on the imagery the other key drainageways in this study, such as the East, the Bluestone, and the Tug Fork rivers. Use of the track profile (see Figure 7) and the general map (Figure 2, page 17) will also assist in the understanding of the terrain along the route.

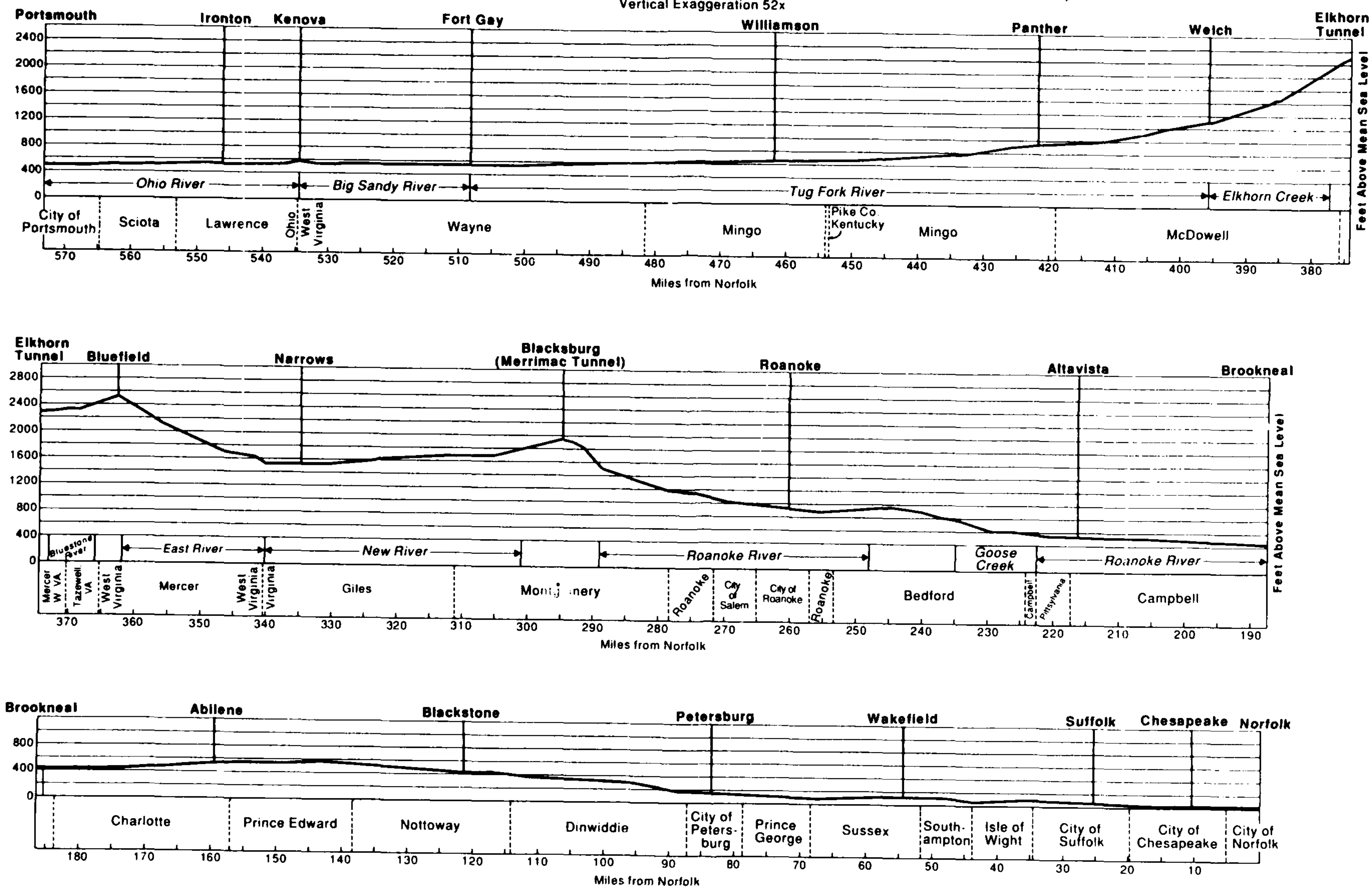
Figure 7. Profile of the Norfolk Southern Railway Between Norfolk, Va., and Portsmouth, Ohio.

A complete vertical profile of the study route at a vertical exaggeration of 52x. Streams proximate to the route are also indicated.

Scale: 1:1,584,000.

Profile of the Norfolk Southern Railway Between Norfolk, Virginia and Portsmouth, Ohio

Vertical Exaggeration 52x



The eastern terminus of the Norfolk Southern main line selected for this study is the Lamberts Point Terminal on the Elizabeth River in Norfolk. However, since the terminal rail yards are not included in the study, the actual analysis of the route commences within the corporate boundary of the city of Chesapeake at Gilmerton, located at the west end of the Norfolk Terminal Yard, 10.3 miles from Lambert's Point.[34]

The route begins in the embayed section of the Coastal Plain of Virginia, a physiographic region of low local relief and gentle slopes formed on unconsolidated Tertiary and Quaternary sands, gravels, clays, and marls. The route leaves Chesapeake and proceeds 15 miles across the northern end of the Great Dismal Swamp to the city of Suffolk. The Great Dismal Swamp, 106,000 acres of wooded wetlands situated at 15 to 25 feet Mean Sea Level (MSL), stretches from southern Virginia into North Carolina. For years, the Swamp kept inland traffic away from Norfolk. Then, in 1853, while clearing the right of way for the Norfolk and Petersburg Railroad, William Mahone[35] conceived a novel plan

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[34]Due to different operational settings, the rail terminal yards in Norfolk, Roanoke, and Portsmouth are not included in the study.

[35]William Mahone was a noted railroad construction engineer who rose to the rank of Major General in the Confederate Army and was known as the hero of the Battle of the Crater. After the Civil War, he was instrumental in restoring the railroad network in war-torn Virginia and later became President of the Atlantic, Mississippi, and Ohio Railroad.

for crossing the Great Dismal Swamp. In addition to clearing and digging drainage ditches, Mahone laid a corduroy mat of trees, roots, and fill to serve as a roadbed for the rails. This same right of way is still in service with the Norfolk Southern (see Figure 8). The route then rises over the Suffolk Scarp to an elevation of 50 to 60 feet (MSL) and proceeds northwest from Suffolk to Petersburg for 52 miles on one of the longest sections of tangent track in the United States.[36] The area along the route is characterized by many small streams and drainageways, terraces, flood plains, and broad, loamy, upland flats. The drainage pattern is dendritic, with most streams having low gradients (gradient for the Blackwater River at Zuni, 11 miles southeast of Wakefield, is 3.3 feet per mile). Stream channels readily overflow during wet periods. Local relief is less than 100 feet,[37] grades are less than 0.50%, and cut and fill areas are extensive along the roadway. The area is characterized by moderately to poorly drained, sandy-clay loam soils.

At Petersburg, the route by-passes the city to the south on the Petersburg Belt Line, parallels Interstate 85,

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[36]The longest stretch of tangent track in the world is across the Nullarbor Plain in southern Australia for a distance of 309 miles; in the United States, the longest stretch is 78.7 miles between Wilmington and Hamlet, North Carolina.

[37]Local relief is the difference in elevation between the highest and lowest points in the area within two miles of the track centerline.

Figure 8. Norfolk and Western Freight Train on the Main Line in the Northwest Corner of the Great Dismal Swamp.

Steam freight locomotives, such as the Class A, 2-6-6-4 shown in this photograph, were used on the Norfolk and Western Railway until 1960.

Source: Norfolk and Western Railway Archival Collection, Virginia Polytechnic Institute and State University Libraries.

and then proceeds west along U.S. Highway 460. Petersburg is located on the Fall Line where the Appomattox River flows off the resistant crystalline rocks of the Piedmont physiographic province onto the weaker sedimentary materials of the Coastal Plain. Although the province boundary is not very distinct topographically in this area, valley floors of the Piedmont are generally much narrower than those of the Coastal Plain. At the Petersburg-Dinwiddie county line, using a maximum grade of 0.60%, the route ascends for seven miles to Sutherland on the crest of a major drainage divide which the track follows for 70 miles to Abilene. The area lying north of the route drains northeast or north into the Appomattox River, while that south of the track drains southeast or south into the Nottoway River. By following the interfluve, the rail line is able to avoid following narrow, sinuous drainageways or constantly climbing and descending stream divides. Between Sutherland and Abilene, the average grade is 0.24%, while the sinuosity ratio averages 1.12 (using the measured 10-mile track segments).[38] The Piedmont topography is gentle and rolling near Blackstone and underlain by granite or gneiss at depth and saprolite near the surface. The area around Abilene is typically a well-dissected upland with the ridges supported

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[38]As will be explained in Chapter IV, the 540 miles of the route are divided into 10-mile track segments known as Railroad Study Units or RSU's. These RSU's are assigned geographical names and sequence numbers.

by granites, gneisses, and schists; local relief is less than 250 feet. Areas of cut and fill are extensive between Burkeville and Abilene. Clay loam soils with clayey subsoils are found throughout this area.

At Abilene, the route joins the former main line of the Virginian Railway and begins a 28-mile, moderate descent to the Roanoke River at Brookneal. The average descending grade is 0.20%, and the sinuosity ratio is 1.10. The topography of the area is a rolling to hilly surface dissected by numerous streams. The average surface elevation for the route ranges from 420 to 550 feet (MSL) with an average local relief of 250 feet. Drainage is well established on the uplands, but many of the flatter interfluves are poorly drained owing to the low permeability of the clayey subsoil. Much of the crystalline rock in this area has weathered into clay and red hematite.

At Brookneal the route turns west along the north bank of the Roanoke River, which it follows for 29 miles to Altavista, and then crosses to the south bank of the Roanoke River for six miles to Leesville. While the average grade along the Roanoke River is moderate at 0.24%, the route encounters increased curvature. The average sinuosity ratio is 1.42. Another index of a valley's crookedness or a railroad's response to terrain can be obtained by measuring in degrees of arc the change in direction of each curve and summing the angles for a total curvature within a specified distance, in this case for 10 miles.[39] Prior to reaching the Roanoke River, the highest total curvature for an RSU had been 55°19' for the Phenix RSU between Abilene and Phenix. For the 10-mile segment along the river east of Altavista, the total curvature is 117°16'. The local relief for the area averages 425 feet, with side slopes as steep as 40%. The gradient for the Roanoke River flowing between Long Island and 10 miles east to Brookneal is 31.25 feet per mile. A major bend in the river three miles east of Altavista is circumvented by the 931-foot long Mansion Tunnel. Soils in this section of the Piedmont are clayey and formed from weathered Triassic sandstone and shale (Danville Basin) as well as greenstone, gneiss, and diorite.

Rather than following the circuitous Roanoke River into Roanoke, the route turns northwest at Leesville to follow Goose Creek for 12.5 miles to Stone Mountain. As the route travels overland from Stone Mountain to Roanoke, the route enters the Blue Ridge physiographic province on a 0.60% grade and levels at Goodview, seven miles west of Moneta (the ascent actually starts six miles east of Stone Mountain at Huddleston). The approximately 22 miles of track through the Blue Ridge between Stone Mountain and the east end of the Roanoke Terminal Yard pass through country with a local relief of 1,000 feet, 50% side slopes, track elevations

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[39] Grey, "A Railroad Across the Mountains: Choosing the Route of the Union Pacific Over the Eastern Rockies," 35.

between 780 and 980 feet (MSL), and extensive areas of cut and fill. The total curvature for the Hardy RSU, between Goodview and Roanoke, is 127°17'. The terrain is developed on the Grenville granites and gneisses of the Blue Ridge thrust sheet. The route rejoins the Roanoke River for the approach into Roanoke through the Roanoke Gap.

The route follows the Roanoke River through the former Virginian Railway yards in south Roanoke to the yard limit 1.5 miles east of Salem. Now in the Ridge and Valley physiographic province, a belt of faulted as well as folded terrain dominated by parallel, linear ridges of sandstone and valleys formed in weaker shales and limestones, the route begins a 27-mile climb to the top of the divide between the Roanoke Valley and the New River Valley at an average grade of 0.90%. The track follows the Roanoke River between Fort Lewis and Poor mountains to Lafayette, where the route joins the North Fork of the Roanoke River, with a stream gradient of 18.6 feet per mile. Ten miles west of Lafayette at Ellett, the route leaves the North Fork and climbs the final six miles on a 1.50% grade to the summit of the divide known locally as Christiansburg Mountain (see Figure 9). The Roanoke River Basin is a hilly topographic surface dissected by deep to very deep drainageways. The area is composed of long, steep side slopes bordering narrow, moderately steep ridges. The local relief in the vicinity of Lafayette is 1,670 feet, and side slopes near

Figure 9. Norfolk and Western Freight Train Descending Christiansburg Mountain into the Roanoke Valley near Elliston, Va.

Source: Norfolk and Western Railway Archival Collection, Virginia Polytechnic Institute and State University Libraries.

Ellett are as steep as 56%. The average sinuosity ratio for the three RSU's between Salem and Merrimac Tunnel is 1.25. Soils in the area on the flood plain of the Roanoke River are silt loams on recent alluvium derived from limestone, shale, and sandstone.

After passing through the 5,176-foot long Merrimac Tunnel on the summit, the route descends at a 0.60% grade for nine miles to Whitethorne, following Slate Branch Creek until it joins the New River (see Figure 10). From Whitethorne, the track follows the New River on the east bank for 29 miles until it crosses at Narrows and rejoins the original Norfolk and Western roadway on the west bank. The route cuts through two major ridges of the Ridge and Valley province: the Walker-Gap Mountain complex at the Giles-Montgomery county line and the East River-Peters Mountain complex at Narrows. While the average grade along this stretch of track is only 0.19%, curves are numerous as the roadway follows the entrenched meanders of the New River. The average sinuosity ratio is 1.56, with the 10-mile segment between Whitethorne and Eggleston having a total curvature of 198°02'. The elevation of the route at Eggleston is 1,670 feet (MSL), with a local relief of 1,330 feet. Steep slopes and vertical columns of limestone and dolomite are encountered along the track (see Figure 11). A silt loam soil weathered from dolomite and limestone and a clayey subsoil are found along the New River terraces. The

Figure 10. Passing Norfolk and Western Coal Trains on the Terrace Above the New River Near Pepper, Va.

Source: Norfolk and Western Railway Archival Collection, Virginia Polytechnic Institute and State University Libraries.

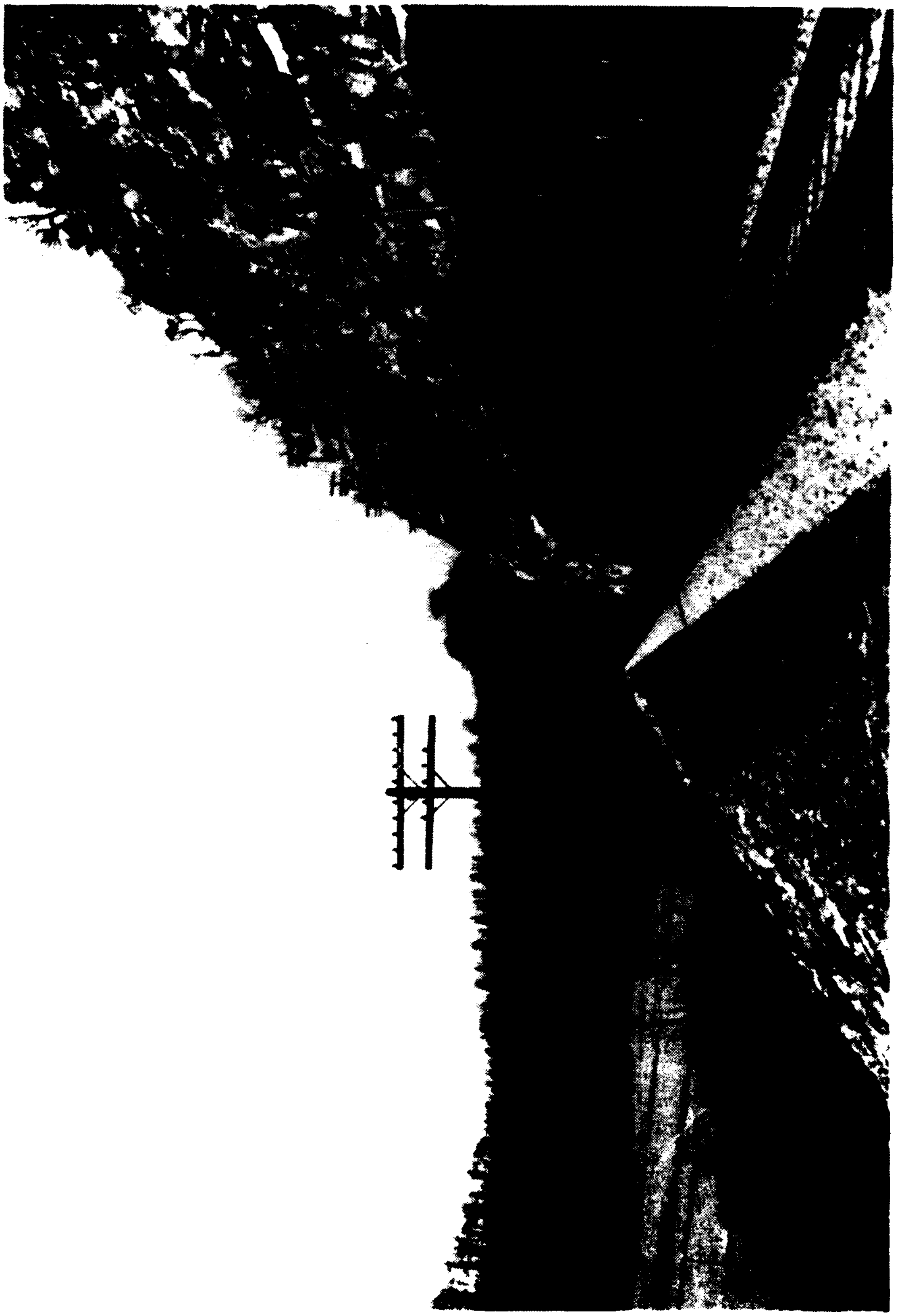

Figure 11. Norfolk and Western Coal Train Westbound Along the New River West of Pembroke, Va.

Source: Norfolk and Western Railway Archival Collection, Virginia Polytechnic Institute and State University Libraries.

ridges, such as Walker, Spruce Run, and Wolf Creek mountains, are composed of sandstone and shale. The gradient for the New River in this section is 4 feet per mile.

Where the route crosses the trace of the Narrows fault one mile east of the New River railroad bridge, the New River abruptly changes course to the southwest (see Figure 12). Rocks in this area are extremely broken and prone to slides. From Narrows, the route proceeds to Lurich, where it turns abruptly to the southwest to Glen Lyn and the mouth of the East River. The New River veers to the southwest to follow the trace of the St. Clair fault. The total curvature for the Glen Lyn RSU is 308°28'.

From Glen Lyn, at an elevation of 1,520 feet (MSL), the route crosses the West Virginia-Virginia state line and follows the East River for 23 miles on a maximum grade of 1.60% into Bluefield, which is located at an elevation of 2,567 feet (MSL). The track follows the narrow valley of the East River, with East River Mountain on the south and Stony Ridge on the north. East River Mountain, the crest of which forms the West Virginia-Virginia state line, is the structural front for the Ridge and Valley province. Stony Ridge marks the eastern boundary of the Appalachian Plateau physiographic province, an elevated and deeply dissected area of low mountains and high hills that is underlain by horizontal, Paleozoic rock strata. In reality, from

Figure 12. Westbound Norfolk and Western Freight Train Just East of Narrows, Va.

Source: Norfolk and Western Railway Archival Collection, Virginia Polytechnic Institute and State University Libraries.

Marlinton, West Virginia, to St. Paul, Virginia, there is no definite escarpment between the Appalachian Plateau and the Ridge and Valley provinces. The boundary is placed along the southeast margin of the coal fields.[40]

For the Ingleside RSU in the East River Valley, the route encounters a local relief of 2,161 feet, has side slopes up to 44%, and crosses the East River six times. While the sinuosity ratio is relatively low at 1.06, the frequent change in direction of the track alignment as it follows the river results in a total curvature of 362°54'. The Jug Neck curve at Blake, seven miles east of Bluefield, has an extreme curve of 12°46'. There are 12 curves greater than 10° on this 10-mile segment of track. The lowland area of the East River Valley is principally limestone, while the valley slopes are largely sandstone and sandy shales.

The summit at Bluefield is the highest point on the Norfolk Southern line in this study. The route proceeds northwest on a downgrade from Bluefield for seven miles along the Bluestone River, a 77-mile tributary of the New River. At Coopers, the route leaves the Bluestone and rises on a 0.80% grade along Mill Creek to Elkhorn Tunnel under Elkhorn Mountain, an extension of Great Flat Top Mountain. This double-track tunnel, 7,107 feet in length, was

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[40]Charles Butts, *Geology of the Appalachian Valley in Virginia*, Virginia Division of Mineral Resources Bulletin 52 (Charlottesvile, Va.: Virginia Division of Mineral Resources, 1973), 5-6.

constructed in 1950 to replace the original single-track, 3,000-foot long tunnel located one-half mile to the east. West of the Elkhorn Tunnel, the route descends on a 1.40% grade for seven miles along Elkhorn Creek to North Fork, then descends on a 0.70% grade for 11 miles to Welch, where the route joins the Tug Fork River. For this stretch, Elkhorn Creek has a gradient of 75.5 feet per mile. The Kimball RSU between Keystone and Welch has a local relief of 1,254 feet, side slopes of 65%, only 400 feet of cut and fill, and a sinuosity ratio of 1.4. Additionally, there are four tunnels in this segment. The soil is silt and sandy loam weathered from colluvial sandstone, shale, siltstone, and coal. From Welch, the route continues along the narrow and winding Tug Fork River Valley for 66 miles to Williamson, the county seat of Mingo County (see Figure 13). This stretch of track is one of the most severe in terms of curvature of any railroad in the eastern United States. For the six RSU's between Welch and Williamson, the average descending grade is a moderate 0.24%, but the average sinuosity ratio is 1.55. The average total curvature is 255°36', and there are 14 curves greater than 10°. The maximum curve of 13°24' is located one-half mile west of Iaeger at the junction of the Dry Fork branch line. Additionally, the route passes through 13 tunnels, the longest of which is the Glen Alum Creek Tunnel at 1,302 feet. The gradient for the Tug Fork River near Panther is

Figure 13. Main Line Track Along the East Bank of the Tug Fork River Near Matewan, W.Va.

Source: Norfolk and Western Railway Archival Collection, Virginia Polytechnic Institute and State University Libraries.

21.3 feet per mile. The average local relief is 1,245 feet with side slopes of 59%. The soils along the Tug Fork River are sandy loam soils weathered from colluvial sandstone, silt, shale, and coal. The route along the Tug Fork River, particularly at Williamson, is prone to severe flooding. Also of interest, the route cuts off a sharp meander between Matewan and Sprigg through the Hatfield Tunnel; by doing so, it passes through 1,500 feet of Pike County, Kentucky.

From Williamson, the route proceeds northwest along the east bank of the Tug Fork for 37 miles to Fort Gay, where the Tug Fork joins the Levisa Fork from Kentucky to form the Big Sandy River. The average grade for this segment of the route is nearly level at 0.02%; but the track continues to encounter frequent curves, though not as severe as in previous sections. The average sinuosity ratio is 1.36 with an average total curvature of 120°52'. The average local relief through this section of the Appalachian Plateau is 900 feet, but side slopes remain moderately steep at 53%. Areas of cut and fill increase from just 400 feet in the Williamson RSU to 8,200 feet in the Glenhayes RSU. Seven tunnels are encountered in this section.

The rail line continues north from Fort Gay in the valley of the Big Sandy River for 25 miles until it crosses the Ohio River at Kenova, West Virginia. The route is nearly level except for a short climb at 0.30% to approach the high bridge across the Ohio River. Curves are not excessive on this stretch as the track follows the relatively wide, 2,500-foot wide flood plain of the Big Sandy River. In contrast, the flood plain of the Tug Fork varies from a width of 300 feet at Welch to 1,800 feet at Williamson. The elevation of the track at Kenova is 600 feet (MSL), with a local relief of 400 feet in an area of low, rounded hills.

After crossing the Ohio River, the track parallels the river for 37 miles on the broad flood plain from South Point, Ohio, to Ironton and to the terminus of the study area at Portsmouth. The elevation of the relatively level route along the Ohio River is 550 feet (MSL) with a local relief of 400 feet. The area is characterized by rolling hills with moderately steep slopes and ridge tops at elevations of 900 feet. The sinuosity ratio for the route between Kenova and Portsmouth is 1.10, making the grade and curvature conditions for this section of the route very favorable. The silt loam soils on the terraces are formed on Quaternary alluvium of shale, sandstone, and conglomerate material. The area is subject to flooding on rare occasions.

Overview of Climatic Patterns

Climatic data were obtained from the National Oceanic and Atmospheric Administration's National Climatic Data Center in Asheville, North Carolina, for Ohio, West

Virginia, and Virginia.[41] Additional climatological information was obtained from the Virginia State Climatology Office in Charlottesville and the West Virginia Agricultural and Forestry Experiment Station in Morgantown. Fourteen climatological data stations were selected along the route (see Figure 2, page 17, and Tables 1, 2, and 3), each lying within 30 miles and 500 feet elevation of its assigned segment of track, a criterion suggested by the Virginia State Climatology Office.[42]

The climate along the route is generally a humid subtropical type with warm, humid summers, relatively mild winters, and uniform precipitation. Because of the standard decrease in temperature with an increase in elevation, the mean summer and winter temperatures are lower at the higher elevations in the Ridge and Valley and the Appalachian Plateau. Mean annual temperatures along the route range from 60.0°F at Hopewell in the Coastal Plain, to 53.5°F at Gary in the Appalachian Plateau, and to 51.4°F at Blacksburg in the Ridge and Valley. Annual precipitation amounts along the route range from 46.93 inches at Suffolk to 39.15 inches at Roanoke.

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[41] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *Climatography of the United States No. 20*, Climatic Summaries for selected Sites in Ohio, Virginia and West Virginia, 1951-1980 (1985).

[42] David E. Stooksbury, Virginia State Climatology Office, interview by author, 23 August 1989, Charlottesville, Va.

TABLE 1

CLIMATOLOGICAL DATA REPORTING STATIONS

			Latitude	Longitude	Elevation	
Station	County	RSU No.	Deg/Min	Deg/Min	Feet MSL	Period of Record
Norfolk, Va.	City of Norfolk	1	36 54 N	76 12 W	24	1951-1980
Suffolk, Va.	City of Suffolk	2-4	36 44 N	76 36 W	22	1951-1980
Hopewell, Va.	Prince George	5-8	37 18 N	77 18 W	40	1951-1980
Blackstone, Va.	Nottoway	9-12	37 05 N	77 57 W	440	1951-1971
Farmville, Va.	Prince Edward	13-16	37 20 N	78 23 W	450	1951-1975
Lynchburg, Va.	City of Lynchburg	17-20	37 20 N	79 12 W	921	1951-1980
Bedford, Va.	Bedford	21-23	37 21 N	79 31 W	975	1951-1980
Roanoke, Va.	City of Roanoke	24-26	37 19 N	79 58 W	1149	1951-1980
Blacksburg, Va.	Montgomery	27-32	37 11 N	80 25 W	2000	1951-1980
Bluefield, W.Va.	Mercer	33-35	37 16 N	81 13 W	2558	1931-1960
Gary, W.Va.	McDowell	36-40	37 22 N	81 33 W	1426	1951-1973
Logan, W.Va.	Logan	41-46	37 51 N	82 01 W	670	1951-1973
Huntington, W.Va.	Cabell	47-51	38 22 N	82 33 W	827	1951-1980
Ironton, Ohio	Lawrence	52-54	38 32 N	82 40 W	555	1951-1980

TABLE 2

ANNUAL CLIMATOLOGICAL DATA
FOR PRECIPITATION (INCHES)

Station	Annual	Max Monthly	Max Daily	Mean Number of Days ≥0.01	≥0.10	≥0.50	≥1.00	Snowfall Annual	Max Monthly	TSTMS*
Norfolk	45.22	13.80	11.40	114.5	78**	30**	13**	7.6	18.9	41
Suffolk	46.93	12.24	6.22	122**	74.0	31.0	14.0	9.5	23.1	40**
Hopewell	44.81	12.92	5.54	120**	74.0	28.0	12.0	10.8	37.5	42**
Blackstone	42.03	13.21	4.04	124**	70.0	28.0	12.0	15.1	29.0	53
Farmville	42.75	12.17	6.62	117**	75.0	31.0	12.0	16.5	32.0	38**
Lynchburg	39.91	11.40	6.27	118.7	77**	29**	11**	18.8	31.8	38**
Bedford	42.10	12.12	6.73	118**	74.0	27.0	10.0	16.1	32.1	39**
Roanoke	39.15	12.36	6.63	118.5	78**	28**	9**	24.0	41.2	49
Blacksburg	39.98	10.29	3.80	132**	81.0	29.0	10.0	28.0	38.5	41**
Bluefield	41.66	10.51	3.57	130**	88.0	29**	9**	33.7	49.2	40
Gary	40.32	11.96	4.29	145**	87.0	28.0	8.0	19.8	17.0	40**
Logan	44.27	9.31	4.02	148**	90.0	30.0	7.0	17.9	18.0	44**
Huntington	40.74	9.26	4.27	139.3	85.0	29.0	8.0	26.5	30.3	61
Ironton	42.31	10.61	3.67	138**	79.0	27.0	8.0	17.7	29.4	46

*Mean number of thunderstorms.

**Interpolated from *Atlas of Virginia Precipitation* and *Climatic Atlas of the United States*.

TABLE 3

ANNUAL CLIMATOLOGICAL DATA
FOR TEMPERATURE (°F)

Station	Mean Temp.		Temp. Range	Mean Number of Days				Freeze Thaw Cycles
				Max Temp.		Min Temp.		
	Warmest Month	Coldest Month		≥90°	≤32°	≤32°	≤0°	
Norfolk	78.4	39.9	38.5	31.9	5.2	55.0	0.0	49.8
Suffolk	77.9	38.9	39.0	37.0	4.0	76.0	0.0	72.0
Hopewell	79.0	39.7	39.3	55.0	4.0	74.0	0.0	70.0
Blackstone	77.2	37.3	39.9	31.0	7.0	80.0	0.0	73.0
Farmville	76.6	37.8	38.8	46.0	4.0	108.0	0.0	104.0
Lynchburg	75.7	35.1	40.6	23.8	10.1	92.3	0.6	82.2
Bedford	75.5	36.7	38.8	28.0	5.0	89.0	0.0	84.0
Roanoke	75.7	35.5	40.2	27.0	11.1	92.3	0.5	81.2
Blacksburg	71.0	30.9	40.1	7.0	20.0	133.0	2.0	113.0
Bluefield	71.8	36.2	35.6	4.0	13.0	107.0	0.0	94.0
Gary	73.2	33.2	40.0	18.0	16.0	126.0	2.0	110.0
Logan	76.5	34.2	42.3	49.0	13.0	109.0	1.0	96.0
Huntington	75.4	32.8	42.6	47.0	21.8	97.7	2.3	75.9
Ironton	76.5	33.4	43.1	42.0	15.0	100.0	2.0	85.0

The climatic patterns of the study area are influenced by the relief of the Appalachian and Blue Ridge mountain systems. For example, when the flow of moist air is primarily from the west, precipitation falls on the windward slopes of the Appalachian Mountains due to orographic lifting, but the New River and Roanoke River valleys are in the rain shadow. Alternatively when the airflow is from the east, precipitation falls on the eastern slopes and foothills of the Blue Ridge while the same river valleys are again in the rain shadow. As a result, both the New River and the Roanoke River valleys are the driest areas of Virginia.[43]

This orographic lifting causes a considerable amount of rainfall during the warm months and moderate snowfall in the winter along the route. As shown in Table 2, ''e stations with the highest annual snowfall are Bluefield and Blacksburg; these are also the stations with the highest elevations (see Figure 7, page 33). Snowfall is common in winter but is normally not of an amount to be significant to railroad operations along the route. Annual snowfall in this study ranges from 7.6 inches in Norfolk to 33.7 inches in Bluefield. A month with a snowfall of 10 inches or greater has occurred once every four years in the Coastal Plain, once every two years in the Piedmont, and almost

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[43]Bruce P. Hayden, *Atlas of Virginia Precipitation* (Charlottesville, Va.: University Press of Virginia, 1979), 20-21.

yearly in the Ridge and Valley and Appalachian Plateau. The record seasonal snowfall for Virginia, 110 inches, occurred in 1977-78 at Mountain Lake, which is located only seven miles northeast of Pembroke on the study route but is situated at an elevation of 3,875 feet (MSL).

Many tropical storms and dissipating hurricanes expend their energy and remaining rainfall on the Piedmont and Coastal Plain as they move northward from the Gulf of Mexico or inland from the Atlantic Ocean. As an example, Norfolk received a maximum daily rainfall of 11.4 inches on 31 August 1964 as a result of Hurrican Cleo.[44]

The climatological data for the study area present few anomalies. As shown in Table 2, the precipitation patterns are very uniform. The mean annual precipitation for the 14 climatological data stations along the route averages 42.29 inches with a standard deviation of 2.2 inches. The mean annual number of days with precipitation greater than 0.1 inch averages 80 days, with a standard deviation of 6.2 days; the extreme maximum daily precipitation averages 5.03 inches, with a standard deviation of 1.45 inches (Norfolk is an outlier with 11.4 inches); the mean annual number of thunderstorms averages 44.1, with a standard deviation of 6.76 storms; and, the 10-year, 30-minute rainfall intensity

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[44]U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *Some Devastating North Atlantic Hurricanes of the 20th Century* (1977), 10.

averages 1.75 inches. Mean annual snowfall averages 19.67 inches with a standard deviation of 6.4 inches.

Regionally the Coastal Plain and Piedmont receive the highest amounts of precipitation, while the stations in the Appalachian Plateau and Ridge and Valley have the highest frequency of precipitation events. Annual snowfall is highest in the Ridge and Valley and Appalachian Plateau and lowest on the Coastal Plain. There is little difference in the annual number of thunderstorms except for the unusually high number of reported storms at Huntington in the western edge of the Plateau.

As shown in Table 3, the temperature regime presents less variation than the precipitation regime. Since this study is based on an east-west linear feature with little latitudinal amplitude (two degrees), most temperature differences are caused by the influence of terrain (elevation and aspect); the moderating effect of the Atlantic Ocean on sections of the route near the coast is an exception. Since the elevation along the route varies only from 15 feet (MSL) at Gilmerton (eastern end of the route) to 2,567 feet (MSL) at Bluefield, temperature differences owing to elevation are minimal. The standard deviation for the mean annual temperature of the 14 reporting stations is 2.27°F. The standard deviation for the annual temperature range is only 1.85°F. The mean temperature of the warmest month varies only 8.0°F, and the mean temperature of the coldest month varies 9.0°F among the stations. Hence there is little spatial variability in the mean temperature data reported by the 14 climatic stations along the route.

The occurrence of very high temperatures (≥ 90°F), freezing temperatures (≤ 32°F), and number of freeze/thaw cycles reflects the regional differences along the route. The stations in the Appalachian Plateau and Ridge and Valley sections of the route have the highest frequency of freezing temperatures and freeze/thaw cycles and the lowest numbers of days with temperatures ≥ 90°F. The stations in the Coastal Plain have the highest frequency of days with temperatures ≥ 90°F and the lowest frequency of freezing temperatures and freeze/thaw cycles.

CHAPTER III

CONCEPTS OF RAILROAD MAINTENANCE OF WAY

The United States Army's Transportation Corps defines maintenance of way as those actions required to maintain and repair a railroad line and its allied structures. It includes regular inspections, keeping track bolts and spikes tight, and replacing worn crossties and rails. It also means cleaning and replacing ballast, as well as constant gaging, surfacing, and aligning of track, particularly along curves. Maintenance of way also includes cleaning ditches and protecting cuts and fills against erosion. Associated bridges, tunnels, fences, and signals must be repaired as necessary. Maintenance of way further includes the movement of personnel, materials, and equipment to locations where derailments, floods, snow, or rockslides have blocked the rail line and disrupted the flow of traffic.[45] In order to better understand railroad maintenance of way, an explanation of the track as a structure is necessary.

Track as a Structure

The track structure's function is to distribute the intense load of the rail wheel on the head (top) of the rail

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[45] Department of the Army, *TM 55-204, Maintenance of Railroad Way and Structures*, (Washington, D.C.: Government Printing Office, 1970), 6.

to a moderate, distributed pressure which the soil underneath the structure can sustain under all environmental conditions. Rail is formed from standard carbon steel and has an approximate yield stress point of 70,000 psi. Rail produced today weighs from 112 to 145 pounds per yard and stands from six to eight inches high. For years, the standard length of rail has been 39 feet. Bolted, 24- or 36-inch long joint bars, arranged to allow for expansion and to reduce rocking and bounce, connect the sections of rail. This joint or connection is always less rigid than the remainder of the rail and allows greater loads on the underlying track structure. To overcome the problem of rail joints every 39 feet, many railroads have switched to what is known as continuous welded rail (CWR). This concept originated on electric, street-car lines in the 1920's but has only become an accepted practice within the last 25 years. Lengths of rail, either new or used (relay), are welded into lengths of approximately 1,500 feet. These rails can be loaded on special rail-carrying cars and transported to the point of installation. The rails are flexible enough to negotiate most curves (up to 14°) on which the "rail train" travels. The installation of rail is restricted to a specified range of temperatures near the upper limit of the expected temperature range.[46] Since the

[46]If the rail is laid at a temperature near the upper end of the annual range for an area, the rails will be in

rails are designed to withstand at least 70,000 psi without deformation, all normal temperature variations can normally be accommodated within its elastic range. However, field welds made in place to join the sections of track must be carefully monitored for quality control since they tend to "pull apart" as the track contracts during extremely cold weather.[47]

When a train wheel moves over the rail, the wheel and the rail tend to flatten at the contact point, forming a small, oval-shaped patch. This contact point has an area of about one-fourth to one-half square inch. If one assumes a 30,000- pound wheel loading (a typical "100-ton" car, when loaded to capacity, can weigh as much as 260,000 pounds) on a one-half square inch contact point, the stress on the rail is 60,000 psi. The track structure must reduce or distribute the 60,000 psi to 20 psi or less, which is the supporting capacity of the underlying subgrade; otherwise, the subgrade will fail and not support the train and track. To accomplish this load distribution (see Figure 14), the steel rail absorbs and distributes the wheel loads to the crossties (usually wooden, but concrete ties are appearing on some rail lines) through the tie plate. The tie plate protects the wooden cross ties from mechanical wear and from

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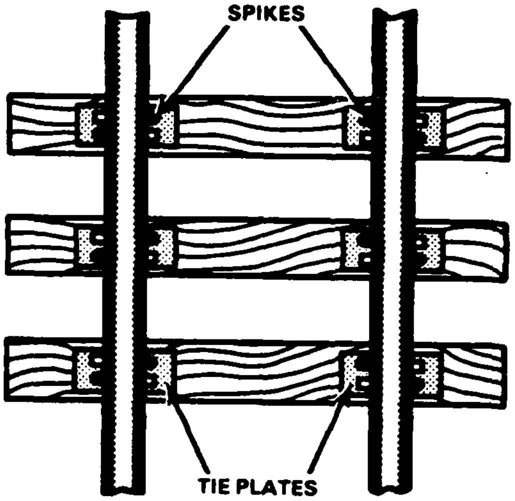
tension, which tends to straighten, rather than buckle, the track at lower temperatures.

[47]John H. Armstrong, *The Railroad--What It Is, What It Does* (Omaha, Nebr.: Simmons-Boardman Publishing Corp., 1982), 32-35.



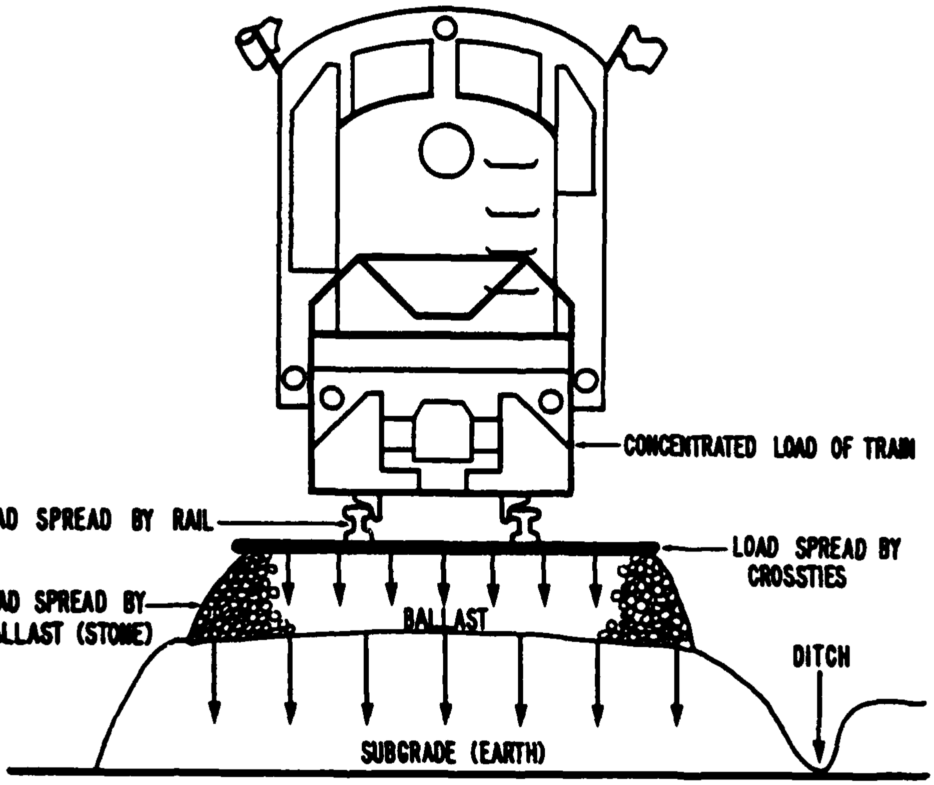


Figure 14. Components of the Track Structure.

the abrasive action of the longitudinally moving rail, caused by heavy traffic loads or extreme temperature changes. The crossties then distribute the tie load to the ballast (specially selected crushed limestone or granite stones, gravel, or slag material) and the ballast distributes the ballast load to the subgrade (the supporting ground at the bottom of the track structure). Subgrades are composed of a variety of soil types; and, depending on local geology, it is possible that the track structure could be sitting directly on bedrock, rather than upon a soil subgrade.[48]

Technically, track conditions cannot be analyzed adequately without considering the loads and forces imparted by passing trains. The two form a track-train system in which changes in one system are reflected in the other. Trains impart forces through wheel and axle loads, braking actions, acceleration, concussion, shock, sway, and on curves, through centrifugal action. Unit coal trains,[49] as found extensively on the Norfolk Southern line in this study, generate high, repetitive wheel loadings that require

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[48]Railway Progress Institute, *Railroad Maintenance Equipment and Materials Manual*, (Alexandria, Va.: Railway Progress Institute, 1986), Chapter 2, 1.

[49]Unit trains use dedicated rolling stock to haul a single commodity, such as coal or iron ore. Coupled with rapid loading and unloading facilities, unit trains result in increased operating efficiency.

even heavier rail sections.[50] As an example, during a November 1989 orientation ride with Norfolk Southern, the author rode in a locomotive that was pulling a 160-car, unit coal train with a total gross weight of 20,061 tons and a length of 8,480 feet (1.6 miles). As the train imparts forces, the track imposes reciprocal effects on the train from curvature, superelevation,[51] low joints, uneven cross level, misalignment, warps, sags and crests, and instability. These reciprocal effects produce responses in the system that affect the safety, ride quality of the train, and the life of the track. Long-term responses that determine the life of the track and other maintenance conditions are not clearly defined and difficult to quantify.[52] It is for those reasons and the fact that this is a geography, rather than an engineering dissertation, that analyses of train-track dynamics will not be discussed in detail.

New rail is laid originally on main lines, where under favorable conditions of tangent (straight) track, it may be

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[50]W. H. Ferryman, "Unit Trains and Their Effect on Track,: in *Proceedings of the 86th Annual Conference of the Roadmasters and Maintenance of Way Association, Chicago, Ill., 1-3 October 1974*, by the Roadmasters and Maintenance of Way Association (Chicago: Roadmasters and Maintenance of Way Association, 1974), 73-75.

[51]Superelevation refers to the additional height that the outer rail is raised above the inner rail on curves, to control the centrifugal force of trains.

[52]Hay, *Railroad Engineering*, 244.

expected to carry up to 600,000,000 gross tons of traffic before replacement is necessary for metal fatigue or head wear. Tracks installed in yards or on branch and secondary lines are usually laid with relay rail which has previously served on a main line. On sharp curves, the rail wear patterns differ between the high and low rails and wear is accelerated. For example, rail on a six degree curve only lasts 30% as long as the same type of track on a tangent roadway. Today, a section of rail may last 60 years before being retired or used as an embankment piling or rock overhang support (see Figure 15).[53]

The remainder of the track structure includes crossties, rail fasteners, ballast, and subgrade. Crossties support the vertical loads of trains and distribute those loads over a wider area of supporting material (ballast). With the ties embedded in the ballast, the crossties provide a means of anchoring rails against longitudinal and lateral movement, and of maintaining its horizontal alignment. Crossties may be made of wood, steel, or concrete. Metal and reinforced concrete are used in many parts of the world such as Europe, where wood is scarce and expensive. Wood is used when available because it has considerable resistance to impact loads and provides a good base into which spikes can be driven. Many species of wood are used for crossties including oak, birch, Douglas fir, gum, maple, and larch,

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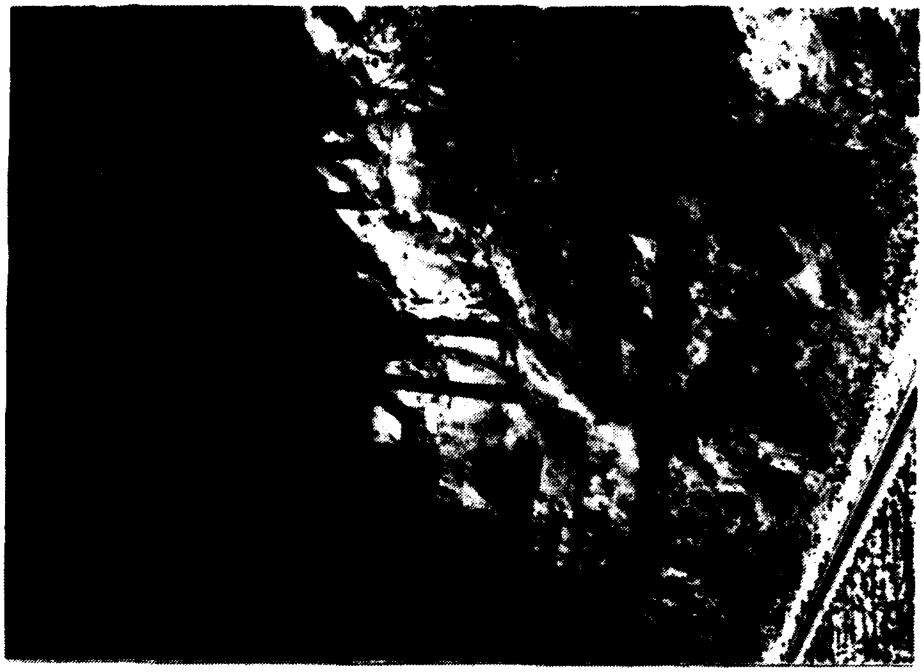
[53] Armstrong, *The Railroad--What It Is*, 33.

Figure 15. Use of Retired Rail as an Embankment Piling (L) at Borderland and as a Rock Overhang Support (R) at Keystone, W.Va.



and ponderosa, lodgepole, and jack pine. The standard crosstie lengths are 8 1/2 feet and 9 feet. Wooden ties, impregnated under pressure with creosote and chromated zinc chloride, may be expected to last from 30 to 35 years under favorable climatic conditions and moderate tonnage. On the study route, ties typically last only 20 to 25 years. This compares with a service life of three to nine years for untreated crossties.[54] Since the Norfolk Southern line between Norfolk and Portsmouth uses wooden ties exclusively, concrete ties will not be discussed.

The track structure must be held in place throughout the layered structural system. Thus, a system of anchors and fasteners is used to restrain the components of the system. As previously mentioned, sections of 39-foot, jointed rail are connected by joint bars. These devices are designed to keep the wheel contact surfaces in line and to provide structural continuity between the rails. Rail spikes or elastic, spring-clip devices restrain the tie plates and keep the rails from shifting sideways. In railroad parlance, these devices maintain the proper gage (4 feet, 8 1/2 inches) and track alignment. Rail anchors are used to restrain track against lengthwise movement caused by the influence of temperature and traffic forces. The effect of the lengthwise movement of rail, or "rail creep," is pronounced on tracks that support the directional movement

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[54] Archdeacon, *The Track Cyclopedia*, 119-122.

of unit trains. In other words, within a railroad network, loaded trains may move in the same direction along track segments to take advantage of reduced grade and curvature. This can produce unique maintenance problems as the rails want to flow in the direction of traffic. These problems are magnified on descending grades where curves are pushed out of alignment.[55]

The railroad term "ballast" is possibly a carryover from the use in early track systems of sand and gravel that had been used previously as ballast in ships. Ballast consists of some type of granular material laid over the subgrade in which the crossties are embedded. The purpose of railroad ballast is: (1) to provide rapid and effective drainage, (2) to hold the crossties firmly in place, thus maintaining alignment and producing uniform support for the track, (3) to provide a material with which irregularities in track geometry can be corrected, and (4) to reduce the amount of dust and deter the growth of vegetation along the tracks. Properly maintained ballast also reduces frost heaves through the draining of surface water and the reduction of capillary action by the relatively wide voids between the ballast particles.[56]

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[55] Jeff A. McCracken, Assistant Division Engineer, Virginia Division, Norfolk Southern Corporation, interview by author, 5 July 1989, Roanoke, Va.

[56] Hay, *Railroad Engineering*, 393-395.

Ballast normally consists of broken or crushed stone, gravel, or slag. The type of ballast used varies greatly and depends on the location of the rail line, the availability of material, and the weight and volume of traffic. Broken or crushed stone is the most desirable ballast for heavy tonnage when broken into sizes ranging from 3/4 inch to 3 1/2 inches. These stones tend to hold the track firmly in place, provide excellent drainage, and resist being crushed into dust and powder. The Norfolk Southern is replacing the limestone ballast originally used by the Norfolk and Western Railway with granite ballast because of its superior quality. Inadequate ballast materials or insufficient depth of ballast overload the underlying subgrade because of insufficient distribution of pressure. As a result, the soil particles in the subgrade churn and permeate the ballast to form "muddy track." Ballast particles penetrate the subgrade to form water pockets and soft spots. Ballast materials that degrade into "fines," particularly soft limestones, create a dust that cements to form an impermeable, inelastic mass that provides uneven support and impedes drainage, tamping, cleaning, and undercutting. Inadequate quality or depth of ballast readily contributes to accelerated wear on ties, rails, and fastenings; to rapid deterioration of track horizontal and vertical alignment; and to subsequent maintenance actions and possible "slow orders."[57]

The supporting ground at the bottom of the railroad track structure is known as the subgrade. The soil properties, construction, and shape of the subgrade are important components in the overall performance of the track structure. The ability of the subgrade to resist deformation or displacement is critical to the maintenance of a stable track structure. The function of the subgrade is to bear the load transmitted to it through the ballast. The subgrade should consist of material that is free of excess moisture and has the physical properties of high internal friction, cohesion, and density and low compressibility, capillarity, and elasticity.[58]

By the maintenance standards of today, many earlier railroads were constructed on unstable subgrades. While the original subgrades were designed to support the train loads of the times, the same subgrades do not provide the necessary support for the heavy trains of today. These old subgrades contribute to many track problems on today's railroads and require constant remedial maintenance. Replacing subgrade at depth is an extreme and expensive endeavor requiring extensive excavation and backfill with new material as well as temporarily closing the line for the

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[57]Ibid., 399-400.

[58]Ibid., 287.

removal of ballast, ties, and rail.[59] As was discussed in Chapter II, much of the track in this study was laid at the end of the last century; in fact, the track alignment between Norfolk and Petersburg was constructed just prior to the American Civil War!

Right-of-Way Maintenance

There are two principal elements of a rail line--sections of straight track and the curves which connect them. Straight tracks are tangent to the arcs or curves; hence the use of the term "tangent" to mean straight track. The path that a railroad follows, made up of the tangents and curves, is called the alignment. The land occupied by the tracks, bridges, fences, tunnels, and other railroad structures is known as the right of way. Within the right of way and of interest to maintenance operations is the roadbed, a strip of terrain with typical widths of 18 feet for tangent single track to as much as 52 feet for curved double track. The different railroad companies use varying standards for roadbed widths in their operations, depending on the number of tracks and the terrain. The roadbed consists of the subgrade and ballast. When viewed from the side, the roadbed reflects the profile or grade of the rail line. The steepness of a grade is given in percent in the United States (the United States also refers to grade using

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[59]Railway Progress Institute, *Railroad Maintenance Equipment and Materials Manual*, Chapter 2, 1-2.

feet of rise per mile). This is determined by dividing the vertical rise by the horizontal (map) length of the grade and multiplying by 100. If a roadbed rises one foot in 100 feet, it is a 1.0% grade. The irregularities of the terrain necessitate some method of compensation to assure smooth and even tracks. This is achieved by grading the right of way as level as possible, excavating cuts, and using fills and bridges where required. The roadbed serves to even out the irregularities of terrain and to distribute the weight of the train over a greater land area. It also raises the track above the adjacent land so as to provide drainage and prevent water from standing on the tracks. Ditches constructed along the side of the tracks provide the necessary drainage.[60]

The ballast in the roadbed allows rainwater and melting snow to enter the subgrade but not to evaporate. Subgrades which are not free draining become saturated and remain that way. Capillary action can also draw ground water a distance of several feet above the water table in fine-grained soils. The absorption of water and consequent softening can reduce the strength of clay and silt subgrade materials to as little as 10% of their original value. Ballast will not provide good drainage for the track structure if the voids

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[60] Department of the Army, *Maintenance of Railroad Way*, 20-23.

between the ballast particles are clogged with foreign material. This material mixes with water to form mud which has a lubricating effect, causing the ballast to lose some of its capability to provide good support to the track structure. Ballast may become clogged, or "fouled," by the following means: (1) spillage of coal from passing coal hopper cars, (2) admixture of water-borne material resulting from floods or inadequate drainage, (3) decomposition of the ballast by mechanical degradation or chemical weathering, (4) addition of airborne dust from adjacent fields, (5) addition of sand from locomotives, and (6) capillary action from the subgrade (see Figure 16 for an example of "fouled ballast" and "muddy track"). A poorly drained subgrade in combination with fouled ballast will lead to a soft roadbed, washouts, and pumping, "muddy track." In cold temperatures excess water in the track structure freezes and creates frost heaves. Freeze/thaw cycles can also weaken the roadbed. With water having such a critical influence on subgrade and ballast stability, the most important aspect of maintenance of way on the roadbed is the control of moving water through the maintenance of adequate drainage systems. These include surface drainage ditches, catch basins, and culverts, as well as sub-surface drainage pipes. Maintaining drainage in ballast is accomplished through: (1) raising the track an inch or two and tamping clean

[61] Archdeacon, *The Track Cyclopedia*, 33, 101.

Figure 16. Example of "Fouled" Ballast and Muddy Track at Whitethorne, Va., in the New River Valley.

ballast under the ties, (2) using a ballast regulator (track machine) to plow the ballast shoulders and break-up mud dams, (3) removing fouled ballast from the area between the ties down to the bottom of the ties and replacing with clean ballast (cribbing), and (4) completely undercutting the track to remove the fouled ballast and replace it with clean material.[62]

Slopes of fill areas (embankments) along the right of way are subject to the continuing effects of gravity and water. Consequently, periodic maintenance is required to restore roadbed shoulders, fill in sinking areas, clean ditches, and prevent erosion by rain or high water from nearby streams. Embankment failures usually result from: (1) failure of the soil in shear, (2) sliding failures along lubricated surfaces in the embankments, and (3) foundation failures. Other landslides and rockfalls may occur in areas of cuts and steep slopes along the right of way. Single rocks and small clusters of rocks are usually involved, rather than the failure of entire rock slopes. These areas of mass wasting involve the generation of a slip surface (plane) that is responsible for the actual movement of the material. This slip surface is generated when the shear

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[62] M. J. Marlow, "Drainage--Its Effect on the Roadway," in *Proceedings of the 91st Annual Conference of the Roadmasters and Maintenance of Way Association, Chicago, Ill., 15-18 October 1979*, by the Roadmasters and Maintenance of Way Association (Chicago: Roadmasters and Maintenance of Way Association, 1979), 75-81.

stress acting along that surface exceeds the shear strength of the slope material.[63]

Maintenance with respect to slides and falls involves frequent inspections to detect slow-moving failures before they become a hazard together with extensive knowledge of the maintenance history of particular track segments. Remedial measures for slides include: (1) strengthening of soils through lime and cement grouting, (2) reducing excess water through a system of drains and pumps, (3) modifying the geometry of the slope, (4) employing structural modifications such as retaining and gabion walls or pilings, (5) bridging over the slide area, and (6) relocating the track away from the base of the slope. Electric slide fences (see Figure 17) installed along the right of way in areas of cuts and steep slopes operate signals to warn trains that the fence has been struck by falling rocks. These fences open electric circuits when pulled apart by the pressure of impinging rocks. To summarize the discussion of maintenance of way along the right of way, many railroad maintenance engineers cite three basic factors--drainage, drainage, and drainage.[64]

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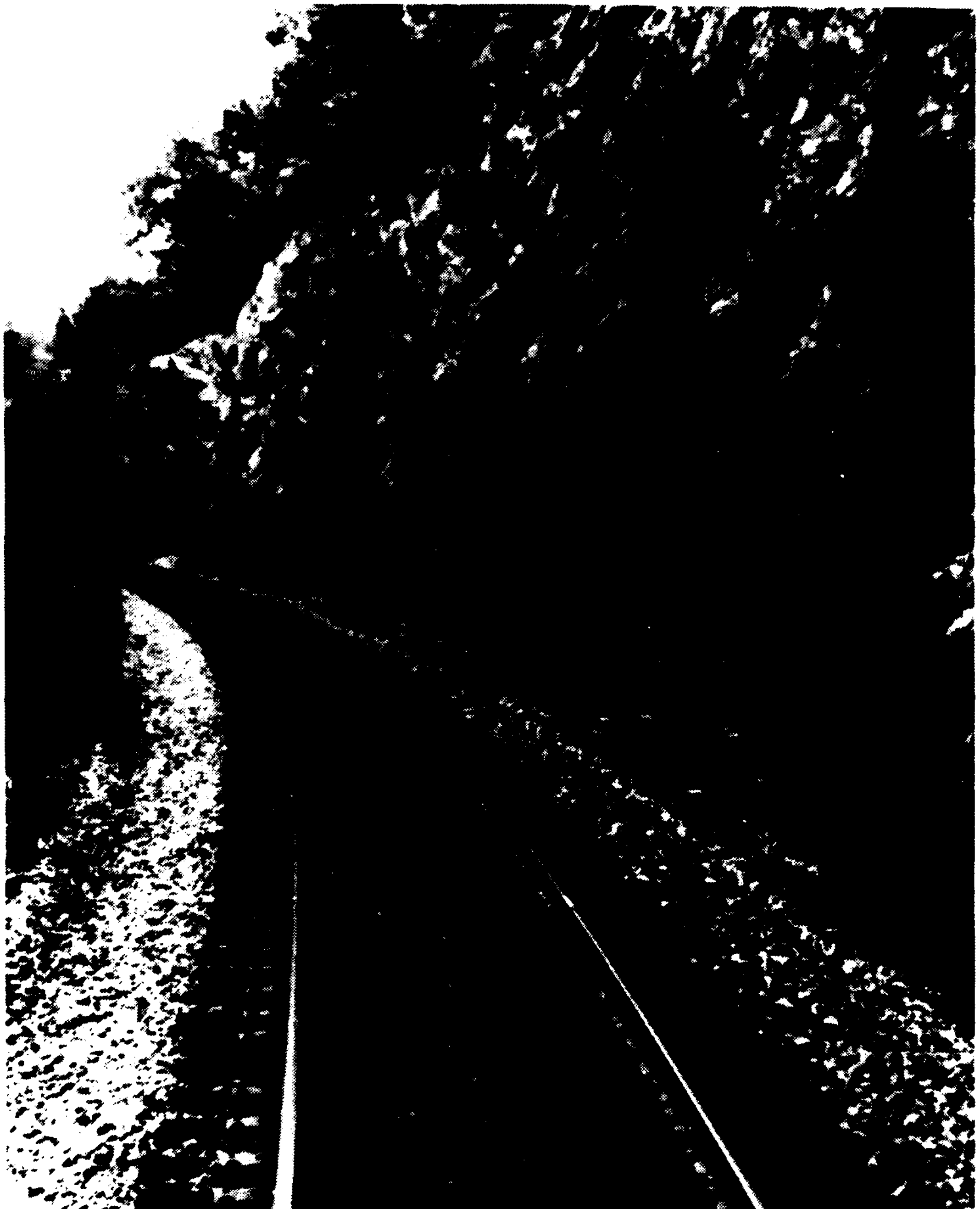
[63]Hay, *Railroad Engineering*, 338-339.

[64]J. M. Johnson, "Slide Control and Prevention," in *Proceedings of the 95th Annual Conference of the Roadmasters and Maintenance of Way Association, Chicago, Ill., 12-14 September 1983*, by the Roadmasters and Maintenance of Way Association (Chicago: Roadmasters and Maintenance of Way Association, 1983), 32-37.

Figure 17. Electric Slide Fence in Service Along a Narrow Cut Two Miles East of the Merrimac Tunnel Near Blacksburg, Va.



Maintaining a right of way that is clear of vegetation and brush does more than improve the aesthetics of the area. Indeed, vegetation control is important to good drainage, safety, and fire control. Continuing technological advances in both herbicides and their application systems have enabled railroads to broaden the bare ground zones along the roadbed. As a result, train crews enjoy clearer sight distances along the track, maintenance workers have safer footing and working conditions, and highway motorists have better views of approaching trains at crossings (see Figure 18). Recently developed herbicides enable railroads to control a broad spectrum of resistant annual and perennial grasses, broad-leaf weeds, brush, and trees.[65]

Nature's constant pressure to invade and establish plant communities in the cleared right of way creates a dynamic and continuous vegetation control problem for railroad maintenance of way.

Heavy, intense rainfall is dangerous to the operation of a railroad when track ballast, ditches, and streams cannot accommodate the runoff and track washouts occur. All too frequently, trains encounter a washout and derail at night when station agents and maintenance personnel are asleep. In the early morning hours of 3 July 1981, a Colorado and Southern Railway train ran into a washed-out

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[65]Mike Wujcik, "Clearing the Track," *Progressive Railroading*, June 1987, 56-58.

Figure 18. Norfolk and Western Freight Train at Glenvar, Va., Seven Miles West of Roanoke.

bridge at Frijole Creek, 16 miles east of Trinidad, Colorado, drowning the engineer and brakeman. Investigators estimated that 11 inches of rain had fallen in the drainage basin above the bridge during the previous four hours.[66]

The interaction of precipitation patterns, sometimes combined with melting snows or frozen ground, and the configuration of slopes and flood plains can result in embankment washouts from fast-flowing swollen streams and from floods that destroy extended portions of rail lines. Washouts, the reduction in track support through the removal of essential ballast and subgrade by water, develop from inadequate drainage systems, as well as from undercutting by streams. However, for this study, washouts are grouped with floods as a maintenance problem rather than with drainage and ballast.

Snowfall can cause serious maintenance problems on main lines from direct fall and accumulation, especially in narrow cuts where wind and lack of direct sunlight for melting contribute to the problem. With drops in temperature, drifting snow can freeze in shallow cuts, forming obstructions sufficient to derail a train. Snow removal is one of the most costly yet least productive

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[66]James T. Hunter, "Early Detection of Storms," in *Proceedings of the 98th Annual Conference of the Roadmasters and Maintenance of Way Association, Chicago, Ill.: 15-17 September 1986*, by the Roadmasters and Maintenance of Way Association (Chicago: Roadmasters and Maintenance of Way Association, 1986), 30-31.

activities with which railroads have to deal. Railroads have always had to contend with snow removal, some under more severe conditions than others.[67] Severe winter snow storms are rare on the rail line between Norfolk and Portsmouth, but a system for fast, efficient, and safe snow removal must be ready to prevent interruptions to traffic and the adverse effects to shippers. During the winter of 1946-47, Bluefield received 101.4 inches of snow, with 49.2 inches falling in February.[68]

Below-freezing temperatures and ice can have serious consequences for track ballast and subgrade depending on the duration and frequency of freeze/thaw cycles, drainage conditions, and the soil character of the subgrade. Frost heaving occurs when the moisture in the ballast and subgrade freezes and expands, disturbing the cross-leveling and alignment of the rails. Where drainage is inadequate, ice formation on the track and in cuts and tunnels can form in amounts sufficient to stop or derail a train (see Figure 19). Track switches and moveable joints may become frozen

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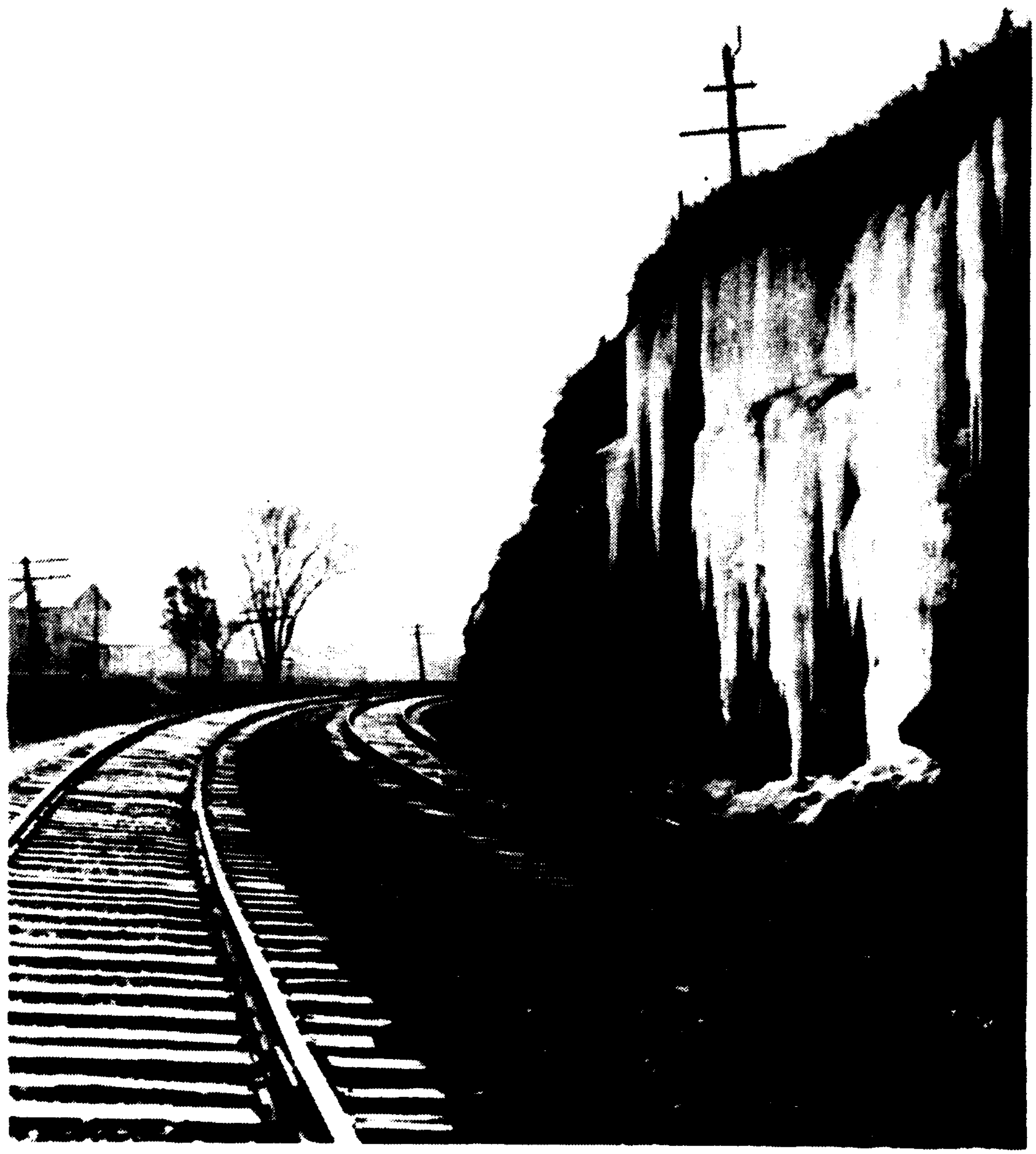
[67] E. J. Summers, "Methods of Snow Removal," in *Proceedings of the 93rd Annual Conference of the Roadmasters and Maintenance of Way Association, Chicago, Ill., 14-16 September 1981*, by the Roadmasters and Maintenance of Way Association (Chicago: Roadmasters and Maintenance of Way Association, 1981), 138-139.

[68] Robert O. Weedfall and W. H. Dickerson, *The Climate of Bluefield, West Virginia* (Morgantown, W.Va.: West Virginia Agricultural Experiment Station, 1971), 3.

Figure 19. Ice Formation Along Curve West of Williamson, W.Va.



and inoperative at temperatures below freezing when combined with moisture from rain, sleet, or snow.[69]

Ice storms occur when supercooled rain or sleet falls and freezes on contact with frozen ground. Ice-laden wires, trees, and sections of pole lines snap and fall, interrupting communications and signal operation and sometimes blocking the track. While most of the Norfolk Southern system uses microwave and radio communications and buried communication and signal cables, above-ground lines and poles are still found throughout the Pocahontas Division. Ice storms also create difficult and hazardous working conditions for maintenance personnel, as tools, materials, walkways, and tracks become covered with ice.[70]

Rail and Tie Maintenance

An important characteristic of the track structure is that all of its components, except for the subgrade which should stabilize with age, wear out and can be replaced on an individual basis without a major interrruption to traffic. Worn-out or defective rail is removed and replaced; defective crossties are identified by inspectors and replaced and ballast is either cleaned or replaced with new material. Over time, the entire track can be replaced

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[69] William W. Hay, "Effects of Weather on Railroad Operations, Maintenance and Construction," *Meteorological Mohographs* 2 (May 1957): 11-12.

[70] Ibid., 19.

without a major interruption. On main line track, such as the one in this study, the replacing of rail and ties is usually handled on a production-line basis using a set of automated rail and tie maintenance machines. These specialized devices lift the entire rail and tie system clear of the ballast; remove and clean the ballast; add additional ballast; and return, realign, and tamp the track in its new bed. Entire sections of rail are replaced in a similar manner. These maintenance machines perform virtually all necessary operations such as spike-driving, shifting the track to the proper horizontal and vertical alignment, removing and installing crossties, and dressing and tamping the ballast.[71]

To ensure that the rails are aligned properly and in good shape, the Federal Railroad Administration (FRA), as well as private firms and railroad companies, operate special monitoring units known as track geometry cars. As the cars move over the rails, sensors mounted on the underside generate electronic signals that lead into an onboard computer. The sensors measure track width, surface uniformity, alignment, elevation, curvature, and warp. Real-time information is provided in the car while the data is also stored on magnetic tape. The FRA inspects all of the nation's high speed (greater than 30 mph) track every

[71] Armstrong, *The Railroad--What It Is*, 40.

two years. Individual railroad companies inspect on a more frequent basis.[72]

Actual rail defects such as transverse and compound fissures, horizontal and vertical split heads, shelling (see Figure 20), and weld defects are detected by special detector cars using ultrasonic and magnetic induction systems. Sperry Rail Service of Danbury, Connecticut, is one of the world leaders in ultrasonic-induction track inspection systems.

High ambient temperatures, particularly those above 90°F, can cause excessive rail expansion. Rail expands .0000065 feet per foot of length per Fahrenheit degree rise in temperature. With the absence of gaps in continuous welded rail (CWR), the rails have no room to expand longitudinally. Without allowing for this thermal expansion, high longitudinal stresses can form in the rail, forcing it to buckle or form "sun kinks," resulting in irregular track and possible train derailments. Jointed rail allows for some thermal expansion. Conversely, in extremely cold weather, rail will contract longitudinally. A standard 39-foot section of rail at 50°F would be 3/16 inch shorter at -50°F. Cold weather may contract the rail to such an extent that it tends to break or "pull apart" at weak spots, especially at field weld sites on CWR. Again,

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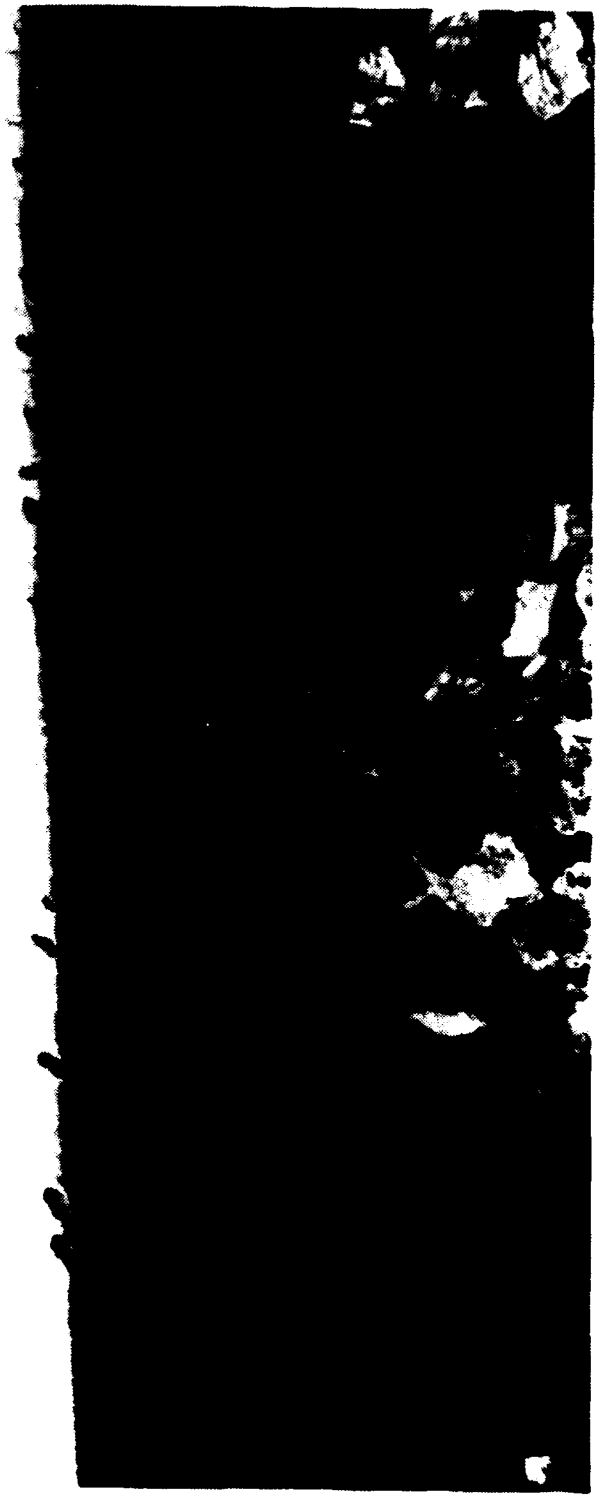
[72] Wilbur Martin, "Riding the Rails to See If They're Safe," *Transportation USA*, Summer 1980, 6.

Figure 20. Example of a Surface Rail Defect, Shelling, Discovered on Curved Track at Ripplemead, Va., in the New River Valley.

this is a dangerous track condition and must be monitored closely by maintenance personnel.[73]

It should be noted that track maintenance on bridges and in tunnels presents unique problems for rail and tie maintenance. Bridges may be either ballasted-deck, which has a solid flooring on which a conventional roadbed is placed, or more likely, the open-deck type, where the crossties are fastened directly to the bridge timbers without the use of ballast. The track over ballasted-deck bridges is maintained by conventional methods. However, on open-deck bridges, for example, to raise and surface the track requires the more complicated use of shims or changing the size of the ties. The principal problem of maintenance in tunnels is the close and limited space in which to work. Raising the track cannot be done without considering carefully the height clearance of passing trains. Similarly, side clearance is a factor when curve realignment is required. Working in tunnels also requires special equipment such as lights, exhaust fans, and low-profile cranes and graders. While tunnels can provide shorter routes with reduced curvature and protection from snow and

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[73] Rail Progress Institute, *Railroad Maintenance Equipment and Materials Manual*, Chapter 4, 6-7.

slides, they usually are difficult and expensive to construct and maintain.[74]

With only a few exceptions, the 34 tunnels along the study route between Norfolk and Portsmouth are unusually wet and muddy and require extraordinary maintenance of way efforts. Interestingly, Ayres, in his study of the Denver and Rio Grande Western Railroad between Denver and Granby, Colorado, found that major maintenance costs for tunnels had been virtually eliminated. Water seepage through the tunnels and onto the roadbed had been controlled by concrete lining or guniting (spraying with a rubber substance) the tunnel walls. In some tunnels, the natural rock was hard and dry enough not to require any lining treatment.[75]

In concluding this section of Chapter III on rail and tie maintenance, it is important to mention briefly the service life of rail. The service life of rail is a function of tonnage, axle loads and speed, the amount of curvature, gradient, subgrade and ballast support, and the standard of maintenance. On tangent track and curves up to 4°, direct wear or abrasion has no practical effect in

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[74] S. J. Buckley, Engineer of Structures, Norfolk Southern Corporation, interview by author, 7 June 1989, Atlanta, Ga.

[75] Ayres, "An Investigation of the Geography of Maintenance Costs on the Denver and Rio Grande Western Railroad," 10.

reducing rail life.[76] Surface deterioration does not usually begin until the passage over the rail of 100 million gross tons. After 100 million gross tons, the effects of abrasion become more significant, particularly as curvature increases over 4°. Curve wear is the limiting rail life factor for curves over 7°, depending on whether or not rail lubricators[77] are in use on the curves. Rails on curves of 7° or greater without rail lubricators receive less than 22% of the rail life of equivalent tangent track and less than 48% even with rail lubricators. Gradient also has an effect on rail life due to excessive wear and abrasion from braking action and locomotive sanding. Rails on grades between 1.0 and 1.5% receive only 90% of the rail life of equivalent level-grade track.[78] These rail service life factors of curvature and grade will be important factors in this study.

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[76]In the United States and Great Britain, curves are designated by degrees. The degree of curvature is the amount of central angle subtended by a chord of 100 feet. Many other countries designate curves by length of the radius.

[77]These track-side devices apply a coating of grease or graphite to the flanges of passing wheels using a treadle-like device adjacent to the rail that depresses as the wheel moves over it. Rail lubricators are strategically placed at the approach to sharp curves or a series of closely-spaced, short curves.

[78]Hay, *Railroad Engineering*, 527-531.

CHAPTER IV

PROCEDURE

Location of Problem Areas for Maintenance of Way

The incidence and location of maintenance problems are, in this paper, considered as dependent variables, so that the effects of climate and terrain can be quantified and placed in a spatial context. Initially, maintenance cost data along the route were to be analyzed to determine quantitatively the location of high and low cost maintenance activities. Unfortunately, the Norfolk Southern, like many railroads, does not maintain finely segmented cost data. Their maintenance costs are aggregated at division level, such as Roanoke (Virginia Division) or Bluefield, West Virginia (Pocahontas Division), and then reported to the Atlanta office. A means to identify how much was spent for a specific maintenance activity at a specific location on a particular day simply does not exist. Therefore the location of maintenance problem areas had to be determined through two other methods, (1) field inspections, and (2) examination of annotated track charts.

The entire 560-mile route was personally inspected during the summer of 1989 using a Norfolk Southern "hy-rail"vehicle (see Figure 21). On each occasion, the author was accompanied by the Assistant Division Engineer and/or

Figure 21. Hy-rail Vehicle at Nemours, W.Va., on Ascending Grade from Bluefield to Elkhorn Tunnel.

These are commercial passenger and maintenance vehicles that have been modified with retractable guide wheels for rail travel. They are generally limited in speed to 35 mph or less on the rails.

the Roadmaster (track supervisor) for each particular track segment of the route.

The Norfolk Southern system is divided into 13 geographical divisions to cover the 29,622 miles of track operated over 17,006 miles of road in 20 states. In each division, the maintenance of way is the responsibility of the Division Engineer and his assistant. Within the division, the tracks and roadway, bridges, buildings, and other facilities must be constantly maintained and renewed. Any of these facilities damaged or destroyed by fire, wind, floods, rockslides, or derailment must be quickly repaired, especially if the problem obstructs the safe movement of trains and cargo. Each Division Engineer has Roadmasters assigned to specific sections of track, varying in length from 10 miles (rail yards) to several hundred miles (main line). Roadmasters have the same responsibilities as the Division Engineer for the correct and economical use of manpower, equipment, and materials in maintenance operations as well as the "on-site" responsibility for all derailments, weather hazards, or other emergencies that obstruct the movement of trains.[79]

Throughout the many inspection trips in the Virginia and Pocahontas Divisions,[80] the Norfolk Southern maintenance

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[79]Hay, *Railroad Engineering*, 703-705.

[80]The route selected for study runs in the Virginia Division between Norfolk and the east end of Bluefield and in the Pocahontas Division between Bluefield and Portsmouth.

personnel identified and explained problem areas. Problem area locations were plotted and any special features noted. Photographs were taken of particular areas of interest.

A second method of locating maintenance of way problem areas involved the use of Norfolk Southern Track Charts (see Figure 22). These track charts are large scale (1:4800 horizontal and 1:2400 vertical) representations of each mile of track in the entire Norfolk Southern system. The track charts were distributed by the author to Assistant Division Engineers and Roadmasters for their respective trackage. The maintenance personnel were asked to annotate their track charts to indicate the location of maintenance problems and any other pertinent information. Specifically, the Roadmasters were asked to annotate sections of track that continually or seasonally present problems due to: (1) inadequate drainage, frost heaving, or capillary action (mud-pumping) in the ballast, (2) slides and rockfalls, (3) washouts and floods, (4) separating or buckling and excessive wear of rails, (5) vegetation control and brush cutting, and (6) snow and ice. These problems constitute the major components of railroad maintenance of way.

Through these two methods, sufficient data for the study were generated.

Development of Railroad Study Units

The key step in this study was the investigation of the spatial variability of the maintenance problems along the

Figure 22. Example of a Track Chart for the Seven Miles Between Mileposts N-283 and N-290.

As seen on a typical track chart page, detailed information is presented on:

1. Type and installation date of rails and ballast.

2. Location (using a system of mileposts) of switches, signals, sidings, bridges, tunnels, and crossings.

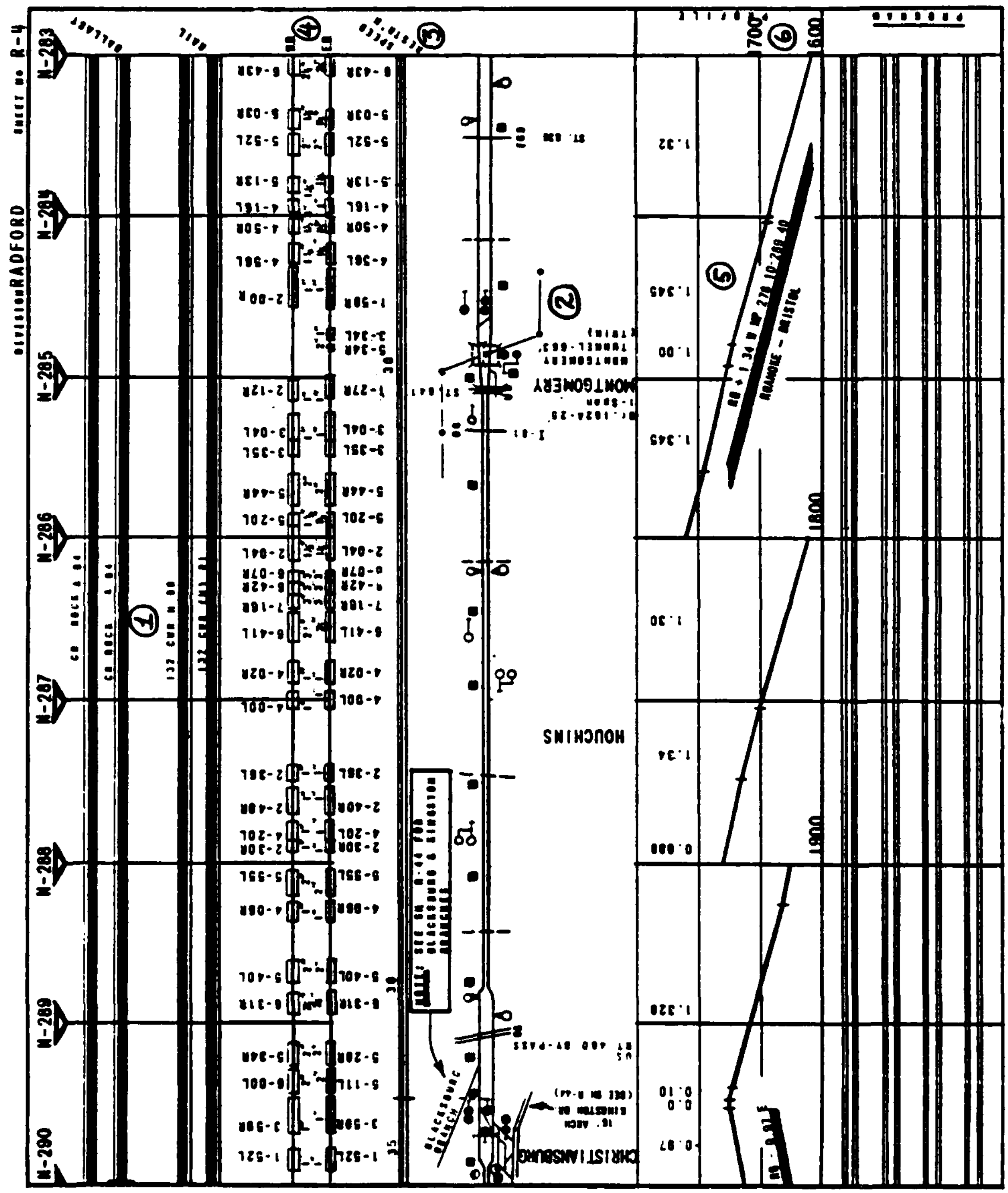
3. Speed restrictions.

4. Location, degree of curvature, and direction of all curves.

5. Percent grade for the alignment.

6. Elevation or vertical profile of the roadway.

Source: Norfolk Southern Corporation.


DIVISION RADFORD
SHEET No R-4
N-283
N-284
N-285
N-286
N-287
N-288
N-289
N-290
MONTGOMERY
HOUCHINS
CHRISTIANSBURG
ROANOKE - BRISTOL
1700
1800
1900
1600

route between Norfolk and Portsmouth as they relate to environmental factors of climate and terrain. For this purpose, the 560-mile study area (route) was divided into 10-mile track segments defined as Railroad Study Units (RSU's). These RSU's provided a framework within which the relationships between climate and terrain could be investigated. The route was first divided into RSU's on the 7.5 minute United States Geological Society (USGS), 1:24,000, topographic quadrangles (10 miles equals 26.46 inches), using a Swiss-made ASI map measurer (curvimeter). In order to cover the entire route between Norfolk and Portsmouth, 85 topographic quadrangles were needed (see Table 4). Next, the same 10-mile segments were marked off on the Norfolk Southern, 1:48,000, Track Charts (10 miles equals 13.21 inches). Each RSU was assigned a geographical name and sequence number, commencing with Number One at Yadkin, Virginia, and ending with Number 54 at Sciotoville, Ohio. A 10-mile track segment is short enough to avoid the inclusion of too many different types of climatic regimes or terrain characteristics and yet long enough to keep the number of segments reasonable.[81] To preclude a gross measuring error, a cross-check for the accuracy of the 10-mile segments was measured with a linear scale.

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[81]Since the rail terminal yards at Norfolk, Roanoke, and Portsmouth are excluded from the study, only 540 miles of the route are divided into 10-mile segments; thus, there are 54 rather than 56 RSU's.

TABLE 4

7.5 MINUTE TOPOGRAPHIC QUADRANGLES[1]

VIRGINIA	Aspen	Anawalt, Va.
	Brookneal	Keystone
Norfolk South	Long Island	Welch
Bowers Hill	Straightstone	Davy
Lake Drummond NW	Castle Craig	Iaeger
Suffolk	Lynch Station	Panther
Buckhorn	Altavista	Wharncliffe
Windsor	Leesville	Majestic
Zuni	Huddleston	Matewan
Raynor	Moneta	Delbarton
Ivor	Goodview	Williamson
Manry	Hardy	Naugatuck
Waverly	Stewartsville	Kermit
Disputanta South	Roanoke	Webb
Disputanta North	Salem	Radnor
Prince George	Glenvar	Milo
Petersburg	Elliston	Louisa
Sutherland	Ironto	Prichard
Church Road	Blacksburg	Fallsburg
Hebron	Radford North	Burnaugh
Wellville	Eggleston	Catlettsburg
Blackstone East	Pearisburg	
Blackstone West	Narrows	OHIO/KENTUCKY
Crewe East		
Crewe West	WEST VIRGINIA/KENTUCKY	Ashland
Green Bay		Ironton
Meherrin	Peterstown	Greenup
Keysville	Oakvale	Wheelersburg
Abilene	Princeton	Minford
Eureka	Bluefield	New Boston
Charlotte Court House	Bramwell	Portsmouth

[1]Quadrangles are arranged in the east to west sequence as used in the study.

Terrain information was obtained by analyzing topographic, geologic, and soils maps procured from the USGS, the Virginia Division of Mineral Resources, and the West Virginia Geological and Economic Survey. USGS 7.5 minute topographic quadrangles provided the major source of terrain data for the route. Satellite imagery from Landsat assisted in the analysis by providing a synoptic view of the study area. Information on soils was obtained from available U.S. Department of Agriculture Soil Conservation Service county soil surveys for counties along the route in Virginia, West Virginia, and Ohio. General soil maps for the states of Virginia and West Virginia were also used.

For each of the 54 RSU's, data on topography, soils, climate, and track were determined. Twenty variables were chosen and arrayed in a matrix with the 54 track segments. These variables and necessary explanations are listed below:

<u>Annual Climatological Data</u>

1. Maximum daily precipitation in inches
2. Number of thunderstorms
3. Number of days with precipitation ≥ 0.1 inch
4. Number of days with precipitation ≥ 1.0 inch
5. Number of days with a minimum temperature ≤ 32°F
6. Number of days with a maximum temperature ≥ 90°F
7. Number of diurnal freeze/thaw cycles--the annual number of days with a maximum temperature of 32°F or below subtracted from the annual number of days with a minimum temperature of 32°F or below

8. Snowfall in inches

Soils Data

9. Subgrade rating from the engineering soil classification system developed by the American Association of State Highway and Transportation Officials (AASHTO) and found in county soil surveys. The worst case rating was used. A rating of A-1 or A-2 indicated excellent to good subgrade while A-4 to A-5 indicated fair and A-6 to A-7 indicated poor.

Terrain Data

10. Cut and fill areas--measured in thousands of linear track feet

11. General description of the geology in terms of structure

12. Landslide incidence and susceptibility--in an area of high incidence, more than 15% of the area is estimated to be involved in landsliding; in an area of moderate incidence, less than 15% but more than 1.5% of the area is involved in landslides; and in an area of low incidence, less than 1.5% of the area is estimated to be involved in landsliding. An area was also rated as an area of high landslide susceptibility if natural or artificial cutting or loading of slopes or unusually high precipitation could cause landslides involving more than 15% of the area. An area was rated as one of moderate landslide susceptibility if natural cutting or loading or unusually high precipitation could cause landsliding involving between 15% and 1.5% of the area. These degrees of landslide incidence and susceptibility were determined by projecting the route across the various landslide zones indicated on a USGS map.[82] Data were also obtained from the author's track inspections and from maintenance personnel.

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[82]Dorothy H. Radbruch-Hall et al., Map--"Landslide Overview Map of the Conterminious United States," (Menlo Park, Calif: U.S. Geological Survey, 1976), Scale, 1:7,500,000.

13. Local relief--the maximum local relief measured in feet for the area within two miles of the track centerline

14. Number of streams (permanent and intermittent) crossed by tracks

15. Side slopes--with the steepest slopes along the tracks measured in percent

Trackage Data

16. Flood potential--as determined by the proximity of the tracks to the highest recorded stage of the associated stream

17. Grade--the absolute value for the mean gradient expressed in percent as determined by measuring the end and midpoint gradients of the RSU

18. Number of tunnels

19. Sinuosity ratio--determined by dividing the segment length of ten miles by the straight-line distance between the end points of each segment

20. Total curvature--the sum of all the curves (degrees and minutes) in the segment as an indicator of directional change

Additionally, the number of maintenance problem areas, as determined by the field inspections and the track charts from the Roadmasters, were totalled for each RSU. The problem areas were divided into: (1) slides and rockfalls, (2) washouts and floods, (3) rail, (4) vegetation, (5) snow and ice, and (6) drainage and ballast.

Thus a preliminary 54x26 matrix was established with the RSU's on the vertical axis and the 20 environmental variables and six maintenance problems arrayed on the horizontal axis. After compiling the data for the matrix, an effort to determine the most significant variables for further study was accomplished through correlation analysis of the 20 environmental variables with the six maintenance categories for the 54 RSU's (see Tables 5 and 6). The analysis of terrain and track variables is presented in Table 7; because of the volume of data, the geology and soils analysis is located in the Appendix.

In order to facilitate the replication of the method used in this study by other individuals or transportation agencies, it was essential that the 20 variables selected initially be reduced to a more manageable number. Four of the preliminary variables--flood potential, geology, landslide incidence, and soil rating--were not included, because they are not interval or ratio scale. Nevertheless, each of these variables was considered significant for further study.

The following variables with correlation coefficient totals greater than 2.0 were also considered significant for further analysis: (1) total track curvature, (2) annual number of days with precipitation ≥ 0.1 inch, (3) side slope, (4) length of cut and fill areas, and (5) track sinuosity ratio. The number of days with precipitation ≥ 1.0 inch was not included because of the selection of the higher rated variable of the annual number of days with precipitation ≥ 0.1 inch. As shown in Table 6, the next rated variable after sinuosity ratio was local relief. This variable was retained because of its significant correlation

TABLE 5

ENVIRONMENTAL VARIABLES FOR CORRELATION ANALYSIS

TCURVE	=	total track curvature
DPG0.1	=	annual number of days with precipitation ≥ 0.1 inch
SSLOPE	=	side slope
DPG1.0	=	annual number of days with precipitation ≥ 1.0 inch
CUTFIL	=	length of cut and fill areas
SINRAT	=	sinuosity ratio
LCLRLF	=	local relief for area within 2 miles either side of track centerline
DMTL32	=	annual number of days with minimum temperature ≤ 32°F
NBRTUN	=	number of tunnels
FTCYCL	=	annual number of diurnal freeze/thaw cycles
MAXDYP	=	maximum daily precipitation
NTSTMS	=	annual number of thunderstorms
MGRADE	=	median gradient for track
SNOWFL	=	annual snowfall in inches
DMTG90	=	annual number of days with maximum temperature ≥ 90°F
NSTRMS	=	number of streams crossed
FLOOD*	=	flood potential from proximate streams
LNDSL*	=	landslide incidence and susceptibility
SOILR*	=	soil rating for subgrade
GEOLO*	=	geology of area

*Not interval or ratio scale and not subject to correlation analysis.

TABLE 6

CORRELATION COEFFICIENTS FOR ENVIRONMENTAL VARIABLES VERSUS MAINTENANCE-OF-WAY PROBLEMS

	Slides and Rockfalls	Washouts and Floods	Rail	Vegetation	Snow and Ice	Drainage and Ballast	Total*
TCURVE	.6702**	.3243***	.8355**	.5871**	.1774	.2703***	2.8648
DPG0.1	.4679**	.4593**	.6011**	.5844**	.4033**	.2240	2.7400
SSLOPE	.6410**	.4390**	.5515**	.4588**	.4828**	.0781	2.6512
DPG1.0	-.4524**	-.5315**	-.4350**	-.5325**	-.5041**	-.1931	2.6484
CUTFIL	-.3848**	-.3661**	-.4350**	-.4388**	-.3737	-.0905	2.0889
SINRAT	.4090**	.4435**	.4447	.5056	.0000	.2718***	2.0746
LCLRLF	.5948**	.2137	.5229	.3026***	.1174	.1435	1.8949
DMTL32	.5143**	.1292	.4557**	.3430***	.2323	.1216	1.7961
NBRTUN	.3083***	.2930***	.2300	.2912***	.2374	.3024***	1.6623
FTCYCL	.5147**	.0100	.4507**	.3452***	.1224	.1868	1.6298
MAXDYP	-.2233	-.2278	-.3674**	-.2976***	-.4041**	.0768	1.5970
NTSTMS	-.1910	.3903**	-.2286	-.1292	.2019	-.2867***	1.4277
MGRADE	.1824	-.3106***	.4626**	-.0316	.1349	.1819	1.3040
SNOWFL	.3682**	.1414	.4395**	-.0173	.2894	-.0141	1.2699
DMTG90	-.2939	.1063	-.2991***	.1385	-.0754	.1113	1.0245
NSTRMS	.1711	-.0173	.1166	.0574	.0556	.2964***	0.7144

*Absolute value.

**Significant at the 0.01 level.

***Significant at the 0.05 level.

TABLE 7

TERRAIN ANALYSIS OF RAILROAD STUDY UNITS (RSU'S)

Segment	RSU No.	LCLRLF[1]	SSLOPE	NSTRMS	CUTFIL	SINRAT	TCURVE	MGRADE	NBRTUN	LNDSL	SOILR	FLOOD
Yadkin	1	26	0	4	5.0	1.00	0 59	0.020	0	low	A-7	50
Suffolk	2	82	0	3	2.0	1.09	1 44	0.249	0	low	A-7	50
Windsor	3	70	0	11	10.0	1.00	2 16	0.325	0	low	A-6	50
Ivor	4	83	0	9	9.0	1.00	2 05	0.310	0	low	A-6	10
Wakefield	5	70	0	9	15.0	1.00	2 02	0.044	0	low	A-6	50
Waverly	6	70	0	11	12.0	1.00	0 50	0.127	0	low	A-6	50
New Bohemia	7	98	1	9	16.6	1.03	10 48	0.187	0	low	A-6	50
SW Petersburg	8	115	3	12	19.8	1.03	3 01	0.434	0	mod/hs[2]	A-7	50
Church Road	9	160	4	4	15.2	1.05	17 42	0.282	0	low	A-7	50
Hebron	10	185	1	1	15.0	1.04	15 22	0.285	0	low	A-7	50
Blackstone	11	190	0	0	3.0	1.20	32 01	0.214	0	low	A-7	50
Crewe	12	204	0	0	4.0	1.04	41 05	0.197	0	low	A-7	50
Burkeville	13	240	3	5	20.0	1.03	4 40	0.335	0	low	A-7	50
Virso	14	206	2	15	22.0	1.14	8 45	0.188	0	low	A-7	50
Abilene	15	190	4	12	18.0	1.34	47 42	0.181	0	low	A-7	50
Phenix	16	212	8	12	21.8	1.06	55 19	0.213	0	low	A-7	50
Aspen	17	270	7	21	17.0	1.13	49 14	0.173	0	low	A-7	50
Brookneal	18	270	26	19	12.2	1.13	68 33	0.210	0	mod/hs[2]	A-7	10
Long Island	19	359	18	11	9.2	1.36	76 53	0.243	0	mod/hs[2]	A-7	10
Altavista	20	429	42	14	8.0	1.80	117 16	0.306	1	mod/hs[2]	A-7	0
Leesville	21	445	65	13	6.0	1.11	72 05	0.176	1	mod/hs[2]	A-7	10
Huddleston	22	400	21	15	10.6	1.14	102 22	0.420	1	high	A-7	0
Moneta	23	500	27	13	12.0	1.09	101 01	0.466	1	high	A-7	50
Hardy	24	1020	53	16	11.8	1.12	127 17	0.176	1	high	A-7	50
Salem	25	1187	20	11	2.6	1.20	56 10	0.636	0	low/ms[3]	A-7	0
Lafayette	26	1667	33	14	4.0	1.16	98 34	0.900	0	low/ms[3]	A-6	0
Ellett	27	1355	56	10	5.8	1.33	132 53	1.200	2	high	A-7	20
Whitethorne	28	820	56	12	4.4	1.20	115 47	0.640	1	low/ms[3]	A-7	30
Eggleston	29	2415	52	10	0.0	1.47	198 02	0.170	0	low/ms[3]	A-7	10

TABLE 7 (continued)

Segment	RSU No.	LCLRLF[1]	SSLOPE	NSTRMS	CUTFIL	SINRAT	TCURVE	MGRADE	NBRTUN	LNDSL	SOILR	FLOOD
Pembroke	30	1330	75	4	0.6	1.66	180 15	0.200	0	low/ms[3]	A-7	20
Narrows	31	2103	63	10	1.2	1.56	154 34	0.208	0	low/ms[3]	A-7	0
Glen Lyn	32	2071	79	4	0.0	1.52	308 28	0.537	0	low/ms[3]	A-7	0
Ingleside	33	2161	44	11	3.0	1.06	362 54	0.714	0	low/ms[3]	A-6	10
Bluefield	34	1606	43	4	1.4	1.04	163 44	1.363	0	low/ms[3]	A-4	10
Bluestone	35	861	73	18	1.4	1.44	394 06	0.818	1	low/ms[3]	A-4	10
Elkhorn	36	1318	60	15	2.0	1.24	154 41	0.988	1	high	A-6	0
Kimball	37	1254	65	18	0.4	1.40	274 45	0.735	4	high	A-4	0
Davy	38	1132	54	20	1.0	1.35	246 04	0.293	7	high	A-4	0
Iaeger	39	1242	52	12	2.0	1.48	231 10	0.405	4	high	A-4	0
Panther	40	1141	42	10	0.4	1.43	221 51	0.233	0	high	A-4	0
Wharncliffe	41	1238	59	9	0.0	1.68	265 51	0.246	1	high	A-4	10
Vulcan	42	1258	74	5	0.0	1.94	378 30	0.122	0	high	A-4	0
Matewan	43	1458	70	8	0.0	1.40	190 07	0.114	1	high	A-4	0
Williamson	44	1329	78	9	0.4	1.27	158 21	0.055	1	high	A-4	0
Naugatuck	45	1134	51	9	3.4	1.54	147 55	0.036	0	high	A-4	0
Kermit	46	880	46	10	2.0	1.14	125 35	0.026	3	High	A-4	0
Webb	47	774	56	10	3.4	1.75	132 45	0.022	3	high	A-4	0
Glenhayes	48	664	42	10	8.2	1.09	93 47	0.003	0	high	A-4	10
Fort Gay	49	620	43	13	7.0	1.41	66 45	0.010	0	high	A-6	10
Cyrus	50	545	41	11	6.0	1.18	49 12	0.017	0	high	A-6	20
Kenova	51	400	39	4	2.4	1.20	112 28	0.121	0	mod/hs[2]	A-6	0
Ironton	52	387	43	6	2.8	1.02	75 36	0.063	0	mod/hs[2]	A-6	0
Haverhill	53	405	58	8	1.8	1.06	9 05	0.123	0	mod/hs[2]	A-7	0
Sciotoville	54	427	60	10	3.0	1.23	31 58	0.123	0	mod/hs[2]	A-6	0

[1]Abbreviations as in Table 5, page 117.

[2]Moderate landslide incidence with high susceptibility.

[3]Low landslide incidence with moderate susceptibility.

with slides and rockfalls and because in combination with the side slope, cut and fill, and sinuosity ratio variables, it provides a reasonable description of the character of the terrain. The variable concerning the annual number of diurnal freeze/thaw cycles was also added on the basis of comments from maintenance personnel. From their experiences, they suggested that of all the climatic variables, the number of diurnal freeze/thaw cycles may be the most important. The remaining variables with totals less than 2.0--annual number of days with mean temperature ≤ 32°F, number of tunnels, maximum daily precipitation, annual number of thunderstorms, mean gradient, annual snowfall, annual number of days with mean temperature ≥ 90°F, and number of streams crossed--were not considered for further analysis in this particular study of the Norfolk Southern railroad. The variable concerning geology was deleted from the matrix because it was difficult to quantify; however, geology will be discussed in the analysis section. Thus the 10 variables--total track curvature, annual number of days with precipitation ≥ 0.1 inch, side slopes, cut and fill areas, sinuosity ratio, local relief, annual number of freeze/thaw cycles, flood and landslide potentials, and soil rating--were selected on the basis of their observed, theoretical, and statistical relationships to maintenance problems.

CHAPTER V

ANALYSIS OF PROBLEM AREAS FOR MAINTENANCE OF WAY

The distribution of the maintenance problem areas for the study route is shown in Table 8. Numbers depicted in Table 8 for the maintenance problem areas represent miles of track in which that particular problem occurred. Thus, a series of problems dispersed within a mile or a concentration of the same problem at a specific point in that mile would both receive a value of one. The maintenance problems will be examined in the order of their frequency of occurrence.

Drainage and Ballast

Maintenance problem areas involving drainage and ballast are the most widespread in the study, involving 42 of the 54 RSU's (78%). This is not surprising in view of the fact that the catalyst for such problems is the dynamic effect of the weight of the cars moving on the tracks and the distribution of that weight through the track structure. This route was selected for study because of its constant, heavy tonnage, speeds, and train frequencies.

Drainage and ballast problems are clearly associated with the engineering characteristics of the underlying soils. The soil classification system developed by the

TABLE 8

PROBLEM AREAS FOR MAINTENANCE OF WAY

Segment	RSU No.	Mileposts	Slides and Rockfalls	Washouts and Floods	Rail	Vegetation	Snow and Ice	Drainage and Ballast	Total
Yadkin	1	N-8.0/N-18.2						2	2
Suffolk	2	N-18.2/N-28.0							0
Windsor	3	N-28.0/N-38.1							0
Ivor	4	N-38.1/N-48.5		1				3	4
Wakefield	5	N-48.5/N-58.4						5	5
Waverly	6	N-58.4/N-68.5						4	4
New Bohemia	7	N-68.5/P-0.6							0
SW Petersburg	8	P-0.6/N-90.2						1	1
Church Road	9	N-90.2/N-100.4							0
Hebron	10	N-100.4/N-110.0						1	1
Blackstone	11	N-110.0/N-120.0						3	3
Crewe	12	N-120.0/N-130.2						4	4
Burkeville	13	N-130.2/B-7.0	1					2	3
Virso	14	B-7.0/B-17.0	2					1	3
Abilene	15	B-17.0/V-147.5						3	3
Phenix	16	V-147.5/V-157.5			1			4	5
Aspen	17	V-157.5/V-167.8			1			5	6
Brookneal	18	V-167.8/V-178.1						5	5
Long Island	19	V-178.1/V-188.2			1	1		6	8
Altavista	20	V-188.2/V-198.7						5	5
Leesville	21	V-198.7/V-209.0	3	1	1			1	6
Huddleston	22	V-209.0/V-219.3	3	1	1			4	9
Moneta	23	V-219.3/V-229.5	7					5	12
Hardy	24	V-229.5/V-239.7	10	1	1		1	1	14
Salem	25	V-246.8/V-257.0		1	1			6	8
Lafayette	26	V-257.0/V-267.3						6	6
Ellett	27	V-267.3/V-277.7			4		2	6	12

TABLE 8 (continued)

Segment	RSU No.	Mileposts	Slides and Rockfalls	Washouts and Floods	Rail	Vegetation	Snow and Ice	Drainage and Ballast	Total
Whitethorne	28	V-277.7/V-288.1	3		1			7	11
Eggleston	29	V-288.1/V-298.3	4					1	5
Pembroke	30	V-298.3/V-308.6	5		3			8	16
Narrows	31	V-308.6/N-334.6	4	1				1	6
Glen Lyn	32	N-334.6/N-344.8	7	1	3				11
Ingleside	33	N-344.8/N-355.3	2		6			3	11
Bluefield	34	N-355.3/N-365.5	4		3		1	1	9
Bluestone	35	N-365.5/N-375.7	5		7	2	2	4	20
Elkhorn	36	N-375.7/N-387.1	4		3	2	1	2	12
Kimball	37	N-387.1/N-398.5	5		4	2	1	3	15
Davy	38	N-398.5/N-411.1	4	2	2	3	1	5	17
Iaeger	39	N-411.1/N-423.5	4		3	3		4	14
Panther	40	N-423.5/N-433.0	4		1	5		2	12
Wharncliffe	41	N-433.8/N-444.5	7	3	7	6		7	30
Vulcan	42	N-444.5/N-455.0	4	3	6	6		6	25
Matewan	43	N-455.0/N-465.3	6	2	3	4	1	7	23
Williamson	44	N-465.3/N-476.5	5	1	1	3	2	3	15
Naugatuck	45	N-476.5/NA-2.3	1					6	7
Kermit	46	NA-2.3/NA-12.8	1	1	1		1	6	10
Webb	47	NA-12.8/NA-22.3	2	3			1	3	9
Glenhayes	48	NA-22.3/NA-32.3	1	1					2
Fort Gay	49	NA-32.3/NA-42.7		1					1
Cyrus	50	NA-42.7/NA-52.0		2			1		3
Kenova	51	NA-52.0/N-572.1	1	1	1		2		5
Ironton	52	N-572.1/N-582.6		1		1	2		4
Haverhill	53	N-582.6/N-592.8		1		1	2		4
Sciotoville	54	N-592.8/N-603.1				1	2		3
	Totals		109	29	66	40	23	162	429

American Association of State Highway and Transportation Officials can be used to rate the engineering characteristics of soils as a railroad subgrade with ratings of A-1 to A-2 considered as excellent to good, ratings of A-4 to A-5 as fair, and A-6 to A-7 as poor (there is no A-3 rating). Table 7, page 119, shows that 40 (74%) of the RSU's in the study have subgrades rated as poor (A-6 or A-7) with the remaining 14 RSU's rated only as fair (A-4 or A-5). The RSU's with poor subgrades begin in the sandy, clay loam soils of the Coastal Plain, continue across the clay loam soils of the Piedmont and clayey subsoils of the Blue Ridge, and into the silty, clay loam soils in the limestone valleys of the Ridge and Valley. The RSU's classified as A-4 begin at Bluefield and continue through the sandy loam soils of the Tug Fork Basin in the Appalachian Plateau. The RSU's along the Big Sandy and Ohio rivers are classified A-6 or A-7, as the route is located on silt loam soils on the flood plains of the rivers.

Many factors other than the engineering qualities of soil account for the widespread problems of drainage and ballast along the route. One factor which contributes to "muddy track" and ballast problems, cited by every roadmaster, was the constant spillage of coal from leaking sides and doors and off the tops of the uncovered coal hopper cars. While this is not an environmental factor *per se*, factors of terrain are associated with this problem.

Roadmaster Steele, responsible for the first 90 miles of the route, identified areas along the roadway where the coal spillage was excessive. Figure 23, at Milepost N-50, clearly shows the excessive amount of coal spillage on the roadway. Note where the buildup of coal starts, just abeam the right-hand signal pole. This demarcation is also the starting point for a 0.5% downgrade on the eastbound track, the track carrying the loaded coal hopper cars to Norfolk. Steele identified similar situations at Zuni and Kilby, where the route also dips to 0.5%. Steele suggests that as the air flow changes over the descending coal cars in these dips, more coal than normal is blown onto the roadway.[83] Is this true throughout the route? No, because the long stretch of tangent track in Steele's area is the only section of the route in which loaded coal trains are permitted to operate at 60 mph and encounter downgrades of 0.5%. Curvature limits the speeds of loaded trains on other areas of the route. This excessive coal spillage is a function of the aerodynamics of the relative wind moving over unstreamlined coal cars of varying frontal heights at 60 mph.

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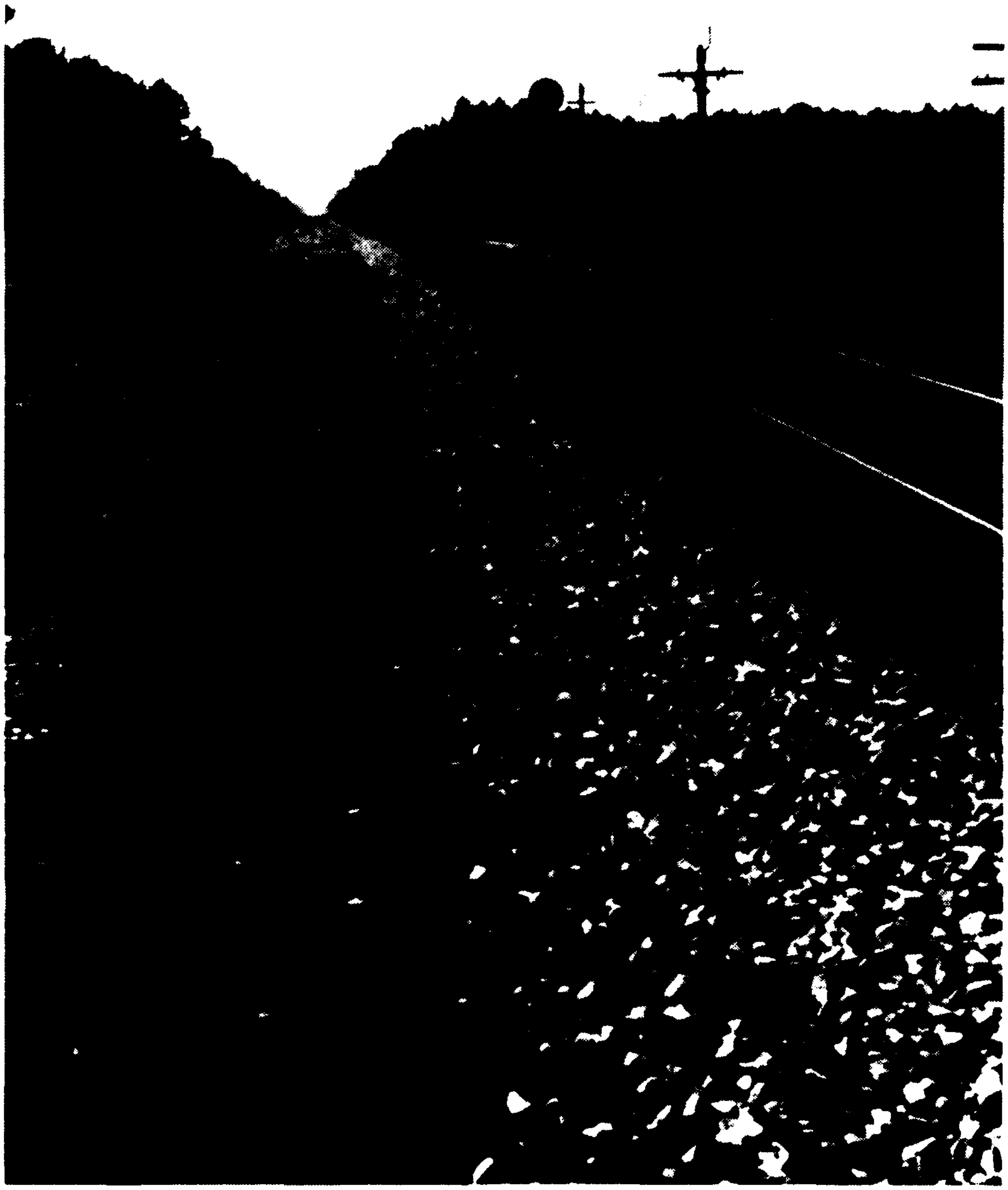
[83] R. P. Steele, Roadmaster, Norfolk Southern Corporation, interview by author, 6 July 1989, Norfolk, Va.

Figure 23. Coal Spillage on the Main Line Near Wakefield, Va.



The high frequency of drainage and ballast problems on the route between the Abilene (15)[84] and Narrows (31) RSU's is partly attributed to the inferior fill materials used by the Virginian Railway, which built this 175 miles of the route and maintained it until 1959. The Virginian Railway used cinders initially as a sub-ballast on top of an inherently poor subgrade soil.[85] As train tonnages increased through time, the cinders disintegrated under the loads and were pushed down into the subgrade. Also, the depth to bedrock is shallow along much of this section of the route, so that the heavy train loads are transmitted from the ballast through the inferior subgrade to the rock, which is ground into mud in a short period of time.[86]

The roadmasters consulted in the study stated that areas of cuts were the most difficult to maintain. Two reasons for this are the persistence of ice and snow and the susceptibility of cuts to rockfalls and slides. An additional problem with cuts is the lack of adequate clearance for the side drainage ditches necessary to drain

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[84] For clarity in referring to particular RSU's, the associated RSU segment number will be included in parentheses.

[85] Cinders were used as ballast because they were inexpensive and drained well; however, they lacked compressive strength and would disintegrate with time. Cinders are only used today in areas of light traffic or on sidings.

[86] Jeff A. McCracken, Assistant Division Engineer, Virginia Division, Norfolk Southern Corporation, personal letter, 14 September 1989.

the roadbed and to intercept surface runoff from rainfall and seepage in the cut slopes. Wide ditches are also desirable to collect rocks and debris that come off the slopes and to provide working space for maintenance operations. Care must be taken to ensure that side ditches do not undercut the stability of the slopes or the roadbed. Side ditches require periodic maintenance to remove excess vegetation, sediments, and colluvial debris. The Virginia Division (Norfolk to Bluefield) averages 9,600 feet of cut and fill per RSU compared to the Pocahontas Division's (Bluefield to Portsmouth) average of 2,300 feet of cut and fill per RSU. This is not to say that the Pocahontas Division does not have problems with maintaining side ditches; during track inspections, the author noticed many ditches that needed cleaning. The side ditches along the route in the Tug Fork Basin are continually filling with sloughed material from the adjacent, steep side slopes.

The correlation analysis suggests a significant, positive association between drainage and ballast maintenance problems and the number of tunnels in an RSU. Drainage and ballast problems are frequently found on the roadway extending from either end of fixed structures (in terms of elevation), such as bridges and tunnels, because the track must remain at a fixed level and cannot be raised for maintenance. Additionally, the track cannot be raised in tunnels because of restricted vertical clearance.

Consequently, tunnels are notorious for having sections of "muddy track." The fact that most tunnels on the route are wet from seepage and poor drainage only adds to the problem. There are 234 bridges and eight tunnels along the route in the Virginia Division and 212 bridges and 26 tunnels in the Pocahontas Division. The worst situation imaginable in terms of drainage and ballast maintenance is to have a series of fixed structures, such as a "bridge to bridge or tunnel" sequence.[87] An example of such an undesirable sequence occurs in the Iaeger (39) RSU at Roderfield, beginning at Milepost N-412 (see Figure 24). At this point, the Norfolk Southern rail line crosses the Tug Fork River at Big Sandy (Bridge 905--244 feet). Two hundred feet later, it enters the Vaughan Tunnel (1,113 feet), which cuts through a finger of Brown's Creek Mountain. The route leaves the tunnel and continues along U.S. Highway 52 for 1,900 feet and then crosses the Tug Fork River (Bridge 906--245 feet); 150 feet later, it enters Roderfield Tunnel (924 feet), which cuts through a finger of Indian Ridge. Three hundred feet after exiting the tunnel, the route crosses the Tug Fork River (Bridge 907--265 feet) and proceeds for 1,750 feet on a 6° curve and crosses the Tug Fork River again (Bridge 907A--245 feet). Seventy-five feet later, the route enters Laurel Tunnel (803 feet) still on a 6° curve; after

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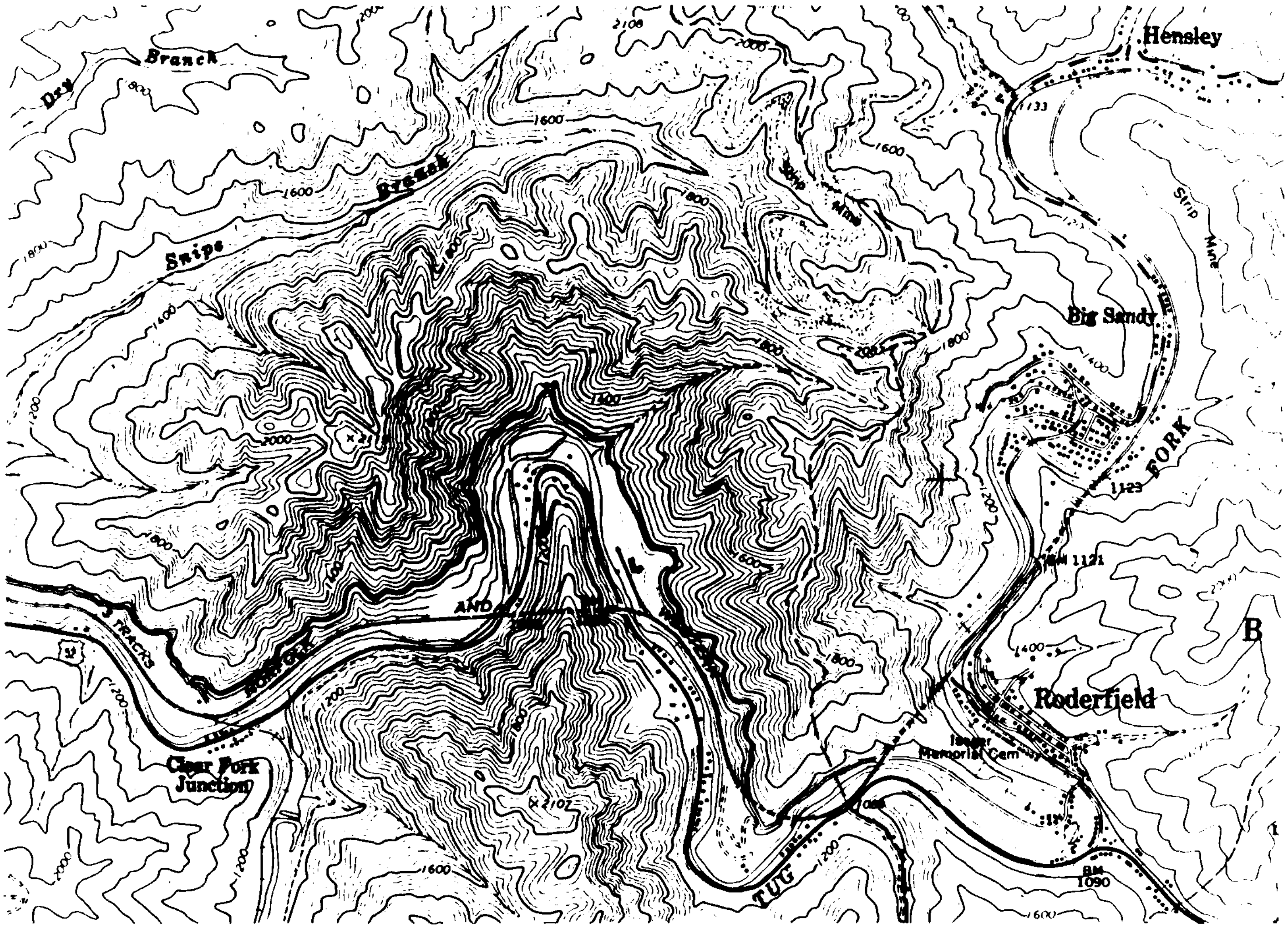
[87]R. L. Meadows, Assistant Division Engineer, Pocahontas Division, Norfolk Southern Corporation, interview by author, 19 July 1989, Bluefield, W.Va.

Figure 24. Norfolk Southern Railway Along the Tug Fork River at Roderfield, W.Va.

A section of the study route taken from a 7.5 minute USGS topographic quadrangle.

Scale: 1:24,000.


Hensley
Dry Branch
Snips Branch
Strip Mine
Big Sandy
FORK
Roderfield
B
Clear Fork Junction
TUG
TRACKS
BM 1090

exiting the tunnel, the route continues for 2,800 feet and crosses the Tug Fork River (Bridge 907B--244 feet) on a 6° curve. One hundred twenty-five feet later, the route enters the Gordon Tunnel (1,271 feet), which cuts through a finger of Sandy River Mountain; 150 feet after exiting the tunnel, it crosses the Tug Fork River once more (Bridge 907C--263 feet). The purpose of this description is not merely to present the mundane details of a track alignment, but to illustrate the demands placed on the maintenance personnel by the climate and terrain of the area. This challenging section of track in the Pocahontas Division, from Milepost N-412 to N-416, a distance of only 2.12 track-miles, has major problems with drainage and ballast maintenance. The "bridge to bridge or tunnel" sequence is found on many other sections of the route in response to the terrain in the western Piedmont, Ridge and Valley, and the Appalachian Plateau.

Drainage and ballast problems are affected by the precipitation along the route in terms of frequency, duration, distribution, and intensity. With the ample and relatively uniform precipitation pattern across the study area, the major environmental factors that contribute to differences in drainage and ballast maintenance problems are the variable terrain characteristics of the drainage basins in terms of the sinuosity of the valleys, combined with the narrowness of the valley bottoms and the steepness of the valley walls. Additionally, the railroad's response to terrain in terms of the location of fixed structures, the location of sections of track on inferior subgrades, and the areas of unusually high coal spill contribute to the problem.

Slides and Rockfalls

Most railroads in this country are built on solid embankments and stable cuts. Early surveyors and engineers constructed railroads across the country encountering a wide variety of soil types, climatic conditions, and terrain features. Generally, they were successful in their efforts; however, certain sections of rail lines, such as the one in this study, continue to experience problems with slope stability. As shown in Table 8, page 123, the rail line between Norfolk and Portsmouth initially encounters only a few areas of slide and rockfall problems until the Moneta (23) and Hardy (24) RSU's in the Blue Ridge physiographic province.[88] There are no apparent problems in the Roanoke Valley, but once the route joins the New River at the Whitethorne RSU, slide and rockfall problems are encountered

[88] In this study, Blue Ridge refers to the physiographic province as described by Fenneman. The province includes all the high mountains underlain by crystalline rocks from northwest Georgia to Pennsylvania. The part of the province north of the Roanoke River at Roanoke, essentially a narrow range of high mountains, is known as the Northern Blue Ridge section. The area south of Roanoke, the erosional escarpment and the mountains behind it extending to Pine Log Mountain, Georgia, is known as the Southern Blue Ridge section.

continuously to Williamson. The number of problem areas decreases from Williamson to Portsmouth.

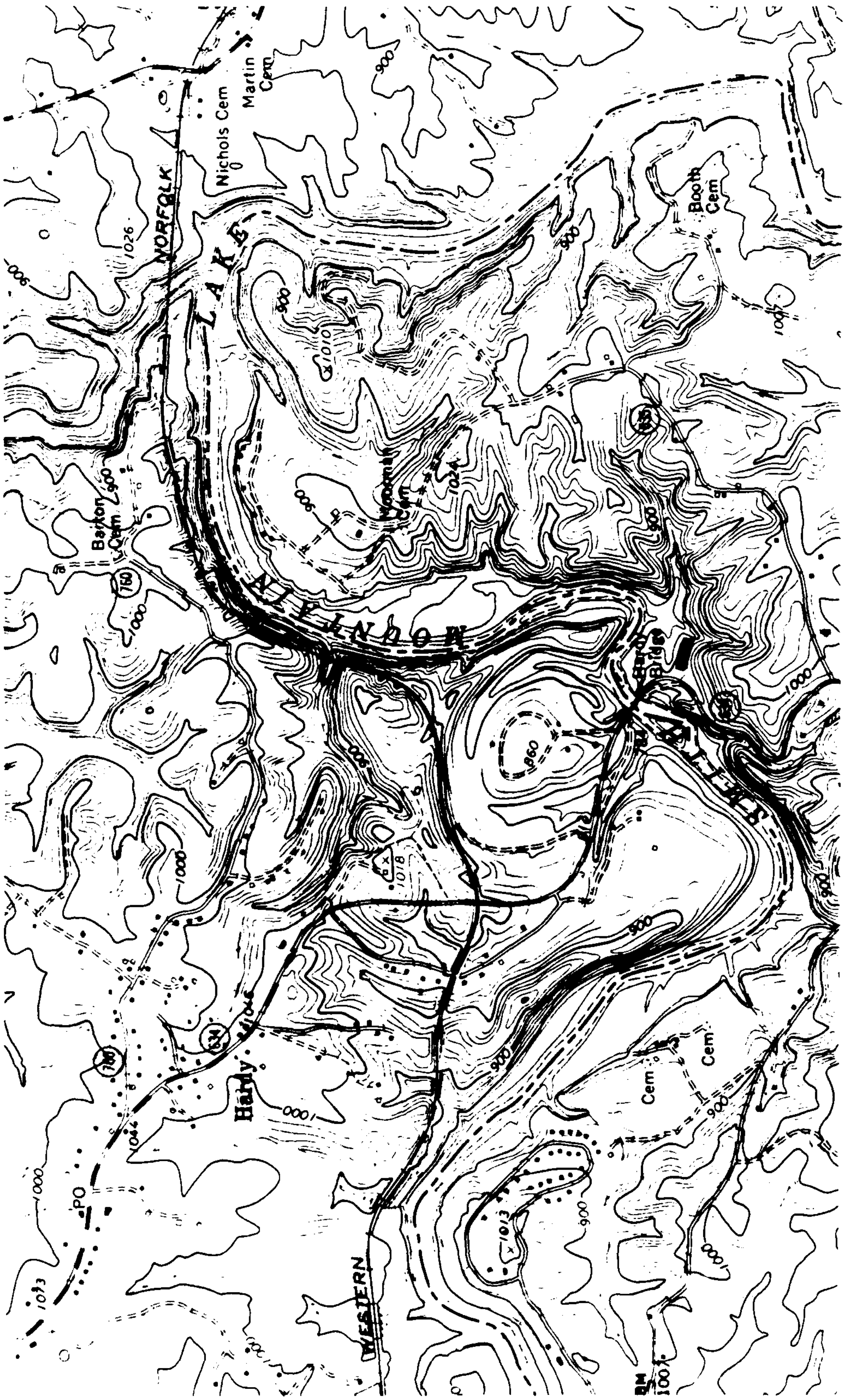
The RSU with the highest number of slide and rockfall problem areas is Hardy (24), with 10, followed by the Moneta (23), Glen Lyn (32), and Wharncliffe (44) RSU's, with seven each. Most of the RSU's in the Coastal Plain, Piedmont, and along the Big Sandy and Ohio rivers had no problems. The correlation analysis indicates highly significant, positive associations between slides and rockfalls and total curvature, side slopes, and local relief. This suggests that the location of slide and rockfall areas could be anticipated along winding segments of track in steep valleys or along steep side slopes. Such terrain conditions are widespread in the Blue Ridge, Ridge and Valley, and Appalachian Plateau.

As the route enters the Blue Ridge, an upland, hilly area developed on gneisses, schists, slates, quartzites, and other metamorphic rocks, the local relief doubles from 500 to 1,020 feet, and the maximum side slopes increase from 27 to 53%. Extensive areas of cut and fill (12,000 feet per RSU) are encountered as the route crosses the drainage divide between Goose and Beaverdam creeks and winds its way to the Roanoke River between Board, Buck and Doe, and Pine mountains. The route crosses the Blue Ridge thrust fault near Hardy, two miles east of the Roanoke-Bedford county line (see Figure 25). Roadmaster Brown, responsible for the

Figure 25. Norfolk Southern Railway Along the Roanoke River at Hardy, Va.

A section of the study route taken from a 7.5 minute USGS topographic quadrangle.

Scale: 1:24,000.



Nichols Cem
Martin Cem
Booth Cem
Barton Cem
NORFOLK
LAKE
Hardy
Cem
Cem
WESTERN

maintenance of this section of track, described a continual problem of "cuts sliding in and fills sliding out." Between 1986 and 1989, Roadmaster Brown dealt with 40 slides on the track in the Hardy (24) RSU.[89]

Slopes in this section are covered by colluvium (a heterogeneous mix of clay, silt, sand, and rock that has moved down slope under the force of gravity) which is highly susceptible to sliding. The Hayesville loamy soil in this area is underlain by clay loam and clay at a depth between 6 and 40 inches. The colluvium is highly permeable, allowing access to both surface and subsurface water. In contrast, the underlying residual clays are relatively impermeable. This difference in permeability allows groundwater to collect along the interface between the materials, so that resistance to sliding is overcome and failure occurs. Other factors affecting the excessive number of slides and rockfalls in this area include the undermining of the toes of the slopes by the many railroad cuts and the increased weight from the buildup of excess water in the slopes and fills, leading to increases in shear stress. This area of the Blue Ridge receives approximately 40 inches of precipitation over 118 days and 49 thunderstorms annually. While definitive precipitation thresholds needed to trigger slides are difficult to determine because of the low density

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[89]M. Brown, Roadmaster, Norfolk Southern Corporation, interview by author, 21 June 1989, Roanoke, Va.

of continuous recording rain gauges in the area and the variable nature of thunderstorm cells, one can say that intense precipitation events are demonstrably capable of producing slope failures, particularly when these events follow periods of persistent, steady rain.[90] The vibrations and shocks induced by the frequent passage of loaded freight and coal trains may also contribute to the problem in this area. Vegetation maintains the stability of slopes by mechanical effects and contributes to the drying of slopes by absorbing part of the groundwater. The required clearing and burning of vegetation along the right of way to reduce fuel loading for fires (required by Virginia forestry officials) exacerbates the problem of slope stability in the Hardy (24) and Moneta (23) RSU's.

A second area of frequent slides and rockfalls is found in the Glen Lyn (32) RSU between Narrows, Virginia, and Kellysville, West Virginia. This RSU includes the route along the west bank of the New River as it cuts between East River and Peters Mountain at the Narrows (see Figure 26) and then turns southwest at Glen Lyn along the East River to Kellysville. Mr. Jeff McCracken, Assistant Division Engineer for Norfolk Southern's Virginia Division, recounted in a letter an incident that occurred in this area on Friday, 18 August 1989. The actual location was on the

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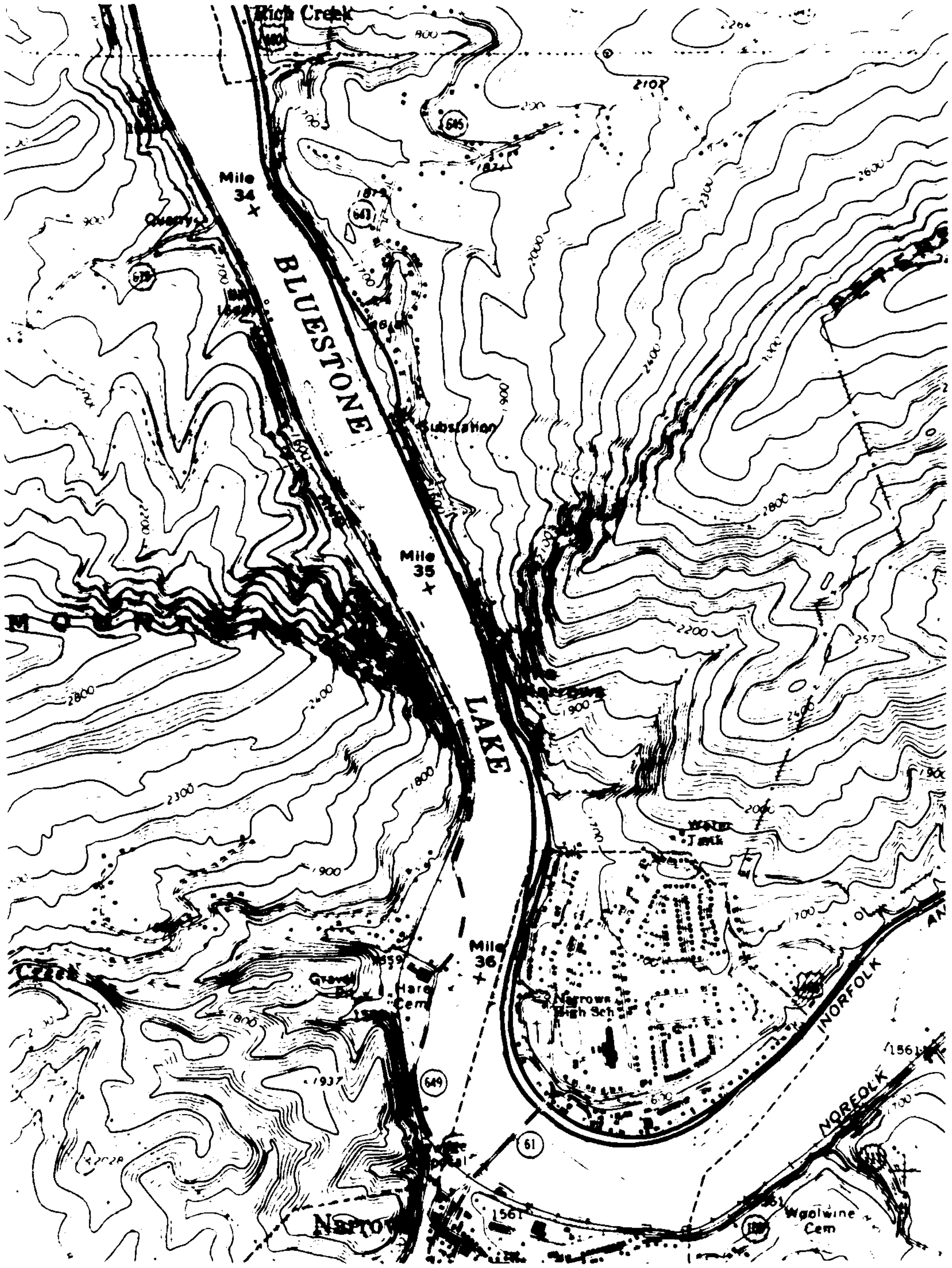
[90]G. Michael Clark, "Debris Slide and Debris Flow Historical Events in the Appalachians South of the Glacial Border," *Reviews in Engineering Geology* 7 (1987): 130.

Figure 26. Norfolk Southern Railway Along the New River at Narrows, Va.

A section of the study route taken from a 7.5 minute USGS topographic quadrangle.

Scale: 1:24,000.



Rich Creek
Mile 34
Quarry
BLUESTONE
Substation
Mile 35
LAKE
Narrows
Water Tank
Mile 36
Narrows High Sch
Gravel Pit
Hare Cem
NORFOLK
Woolwine Cem
Narrows
2800
2300
2600
2400
2200
1900
1800
2000
2100
1700
1561
1937

track between mileposts N-335 and N-337.5, which is the segment of track between Narrows and Lurich. Local relief in this area is 2,071 feet, with maximum slopes of 79% along the track. An isolated storm had dumped approximately six inches of rain in the area between 8:00 am and 12:00 noon. The following is McCracken's description of the event:

> As a result of this rain, a slide came in on an empty westbound coal train derailing one car. There was no damage to the train or track due to the fact that Roadmaster Haroutunian was inspecting the track on account of the rain and immediately stopped the train. While the train was stopped, another slide came in against it, derailing two more cars. In all, a total of seven major slides came in against the main track. Also due to the heavy runoff, a portion of the fill at milepost N-336.5 washed out on the east side of the main track. Approximately 300 tons of stone were required to repair the fill before the track could be returned to service.[91]

McCracken also states that intense, isolated storms, such as the one just described, are fairly common occurrences in the late summer.

Along the Glen Lyn (32) RSU, the route crosses two major geologic faults: (1) the Narrows fault, extending from northeast Giles County, Virginia, and passing one-half mile northwest of the town of Narrows, and (2) the St. Clair fault, extending from Alleghany County, Virginia, across the projection of Giles County four miles northwest of the town of Narrows. Rocks along the traces of the faults in the New River Valley are extremely broken and easily eroded. The fault-crushed sandstones and shales that dip steeply to the

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[91]McCracken, personal letter, 14 September 1989.

southeast in this section of the New River Valley are undercut by the New River as it erodes its channel. The already unstable slopes are further weakened by the Norfolk Southern roadway as well as the roadcuts for U.S. Highway 460 and Virginia Highway 648 along the New River. Thus, a unique combination of climate and terrain contributes to a continual problem of slides and rockfalls in this section of the New River Valley.

A third area of significant slide and rockfall problems occurs in the Wharncliffe (41) RSU and, in fact, along the entire route from Bluestone to Williamson. This portion of the route along Elkhorn Creek and the Tug Fork River is in the Appalachian Plateau physiographic province, the most extensive area of unstable slopes in the eastern United States.[92] The Appalachian Plateau is a deeply dissected area of hills and low mountains underlain by roughly horizontal strata of primarily Mississippian and Pennsylvanian sedimentary rock. The study route proceeds over rocks of the Pottsville Group, composed of the Pocahontas, the New River, and the Kanawha formations. This group is composed of over 50% sandstone with interbedded shale, siltstone, and coal. The extensive and deep surface drainage system in the Plateau exposes these beds in the stream valleys. The shales weather rapidly into clay upon

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[92] Radbruch-Hall et al., narrative from Map--"Landslide Overview Map of the Conterminious United States."

exposure. As previously discussed, water moving along the interface between colluvium near the base of slopes and weathered shale or clay creates a potential zone of weakness or slip surface. Between the Bluestone (35) and Williamson (44) RSU's, the average local relief is 1,223 feet, with average maximum side slopes of 63%. Precipitation averages 42.3 inches annually in this area, with 89 days a year with at least 0.1 inch of precipitation.[93] Rockfalls in this area are also initiated by the effects of water freezing and expanding in rock fissures and joints along steep cliffs and slopes. The number of freeze/thaw cycles averages 103 annually. Removal of surface vegetation, initially by extensive lumbering operations and now by surface coal mining, also increases the potential for landslides. The removal and repositioning of overburden on slopes in the contour mining technique leads to an increase in shear stress, and the use of deep-mining methods removes underlying slope support and alters the pattern of groundwater flow. Thus, as the Norfolk Southern rail line passes through the rich southern coal fields of McDowell and Mingo counties, the human activity of mining combined with the geology, terrain, and climate contributes to the high incidence of slides and rockfalls along this section of the route.

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[93]Climatological data averaged between the Gary and Logan, West Virginia, stations.

The remaining RSU's along the route have few or no reported maintenance problems concerning slides and rockfalls, primarily because the terrain of these RSU's is more stable, and significant side slopes do not occur along the roadway.

Rail Problems

The Norfolk Southern roadmasters were asked to annotate their track charts to indicate the location of specific maintenance problems. With regards to rail problems, the roadmasters located sections of track that: (1) were prone to separating or buckling due to temperature extremes, (2) were prone to frost heaving, or (3) required extraordinary maintenance in terms of surfacing or rail renewal/replacement because of the track location or curvature.

As shown in Table 8, page 123, 25 of the RSU's indicate at least one rail-related maintenance problem area. The two RSU's with the highest numbers of such areas are Bluestone (35) and Wharncliffe (41) with seven areas each, followed by Ingleside (33) and Vulcan (42) with six areas each. All of these RSU's are in the Appalachian Plateau. From Yadkin (1) through the Abilene (15) RSU, or across the Coastal Plain and 60 miles of the Virginia Piedmont, no rail problems were noted. Only seven areas are noted over the next 110 miles from Abilene through the western Piedmont, Blue Ridge, and Roanoke Valley. At the Ellett (27) RSU, where the route ascends Christiansburg Mountain (the divide between the New and Roanoke valleys), four rail problem areas are indicated. As the route proceeds through the New River Valley, one problem area is indicated at Whitethorne (28) and three each in the Pembroke(30) and Glen Lyn (32) RSU's. However, for the next 120 miles, as the route ascends and traverses the Appalachian Plateau from Ingleside (33) through the Williamson (44) RSU's, rail problem areas are indicated in every RSU. For this 120-mile segment, rail problems are indicated at a rate of one per two and one-half miles. As a comparison, for the other 420 miles considered in this study, rail problems occur at a rate of only one per 21 miles.

This concentration of maintenance problems is significantly associated with the amount of curvature, and to some extent the gradient, along the route--particularly curves greater than 7° and gradients greater than 0.5%. For the 12 RSU's, Ingleside (33) through Williamson (44), with significant rail problems, the sinuosity ratio averages 1.40 per RSU, the mean gradient averages 0.51% per RSU, and the total curvature averages an extraordinary 253°30', with 8.67 curves greater than 7° per RSU. These figures are in sharp contrast to the averages for the other 42 RSU's on the route: (1) sinuosity ratio of 1.17, (2) mean gradient of 0.25%, and (3) total curvature of 72°38' with 0.88 curves greater than 7° per RSU. Of the three parameters, total curvature is the most important, as it represents the total change in direction within an RSU and the associated higher wear on the rails. The higher values for total curvature, sinuosity ratio, and gradient reflect the route's response to the surface pattern and valley profiles of the route in that section of the Appalachian Plateau.

Extreme high and low temperatures have an adverse effect on rail maintenance. Of the 10 roadmasters responsible for the maintenance of way of the 540 miles of this study, only four reported any rail problems associated with temperature extremes. As one might expect, the three roadmasters responsible for the RSU's between Bluefield and Williamson all reported temperature-related problems, with the highest number in the Wharncliffe (41) RSU. While regional climatological data for temperature ranges and extremes for this section of track are available from Bluefield, Gary, and Logan, their values alone do not indicate significant relationships between climate and rail problems. For example, the annual temperature range (difference between the mean temperature of the coldest and warmest month) for Gary, West Virginia, in the Appalachian Plateau, is 0.6°F less than Lynchburg, Virginia. Undoubtedly, microclimatic conditions in the deep and narrow valleys of this section of the Appalachian Plateau provide temperature extremes that contribute to the rail problems. In these valleys, the coldest and densest air in an area drains and settles to the lowest levels, while temperature increases with height, producing a valley inversion. In this stable situation, temperature varies directly with elevation. If temperatures fall below freezing, these deep valley areas may develop "frost pockets" and temperatures that are significantly lower than nearby reporting stations.[94] In another microclimatic situation, sections of rail in these valleys may be oriented in such a way that they are exposed to direct sunlight for long periods of time. Steel rail receiving direct sunlight with no wind has been found to be 35°F warmer than the ambient air temperature.[95] Roadmaster Obenchain reported a unique problem of broken rails in a four-mile section of the Ellett (27) RSU. Obenchain is responsible for 140 miles of track (74 miles along the study route) in the Virginia Division. Interestingly, 75% of his broken rail problems occur along this four-mile section of track. This section of track, between Ellett and Yellow Sulphur, ascends the Blue Ridge erosional escarpment from the valley of the North Fork of the Roanoke River in a series of cuts on a 1.5% grade to the

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[94]T. R. Oke, *Boundary Layer Climates* (New York: John Wiley and Sons, 1978), 154-155.

[95]M. E. McGinley, "Methods of Distressing CWR and Maintenance of CWR Under Extreme Temperature Conditions," in *Proceedings of the 95th Annual Conference of the Roadmasters and Maintenance of Way Association, Chicago, Ill.: 12-14 September 1983*, by the Roadmasters and Maintenance of Way Association (Chicago: Roadmasters and Maintenance of Way Association, 1983), 48.

summit of Christiansburg Mountain at the Merrimac Tunnel. Roadmaster Obenchain stated that these rail breaks were due to overnight cold temperatures. He speculated that this section was always colder than reported by area weather stations. During the winter of 1988 to 1989, Obenchain encountered some 60 broken rails in this area, usually at the field weld sites (weakest point in the system).[96] Obenchain's suggestion may be valid. Blacksburg, the climatological reporting station located only four miles from this area, averages 30.9°F for the month of January--the coldest mean monthly temperature in the study. Blacksburg also averages, on an annual basis, 133 days with minimum temperatures below 32°F and 113 freeze/thaw cycles--also the highest values in the study. Cold, dense air that forms on the New River Plateau spills over the escarpment and, in this situation, is funneled along Wilson Creek near the tracks into the valley of the North Fork of the Roanoke River. The Ellett (27) RSU has a total curvature of 132°53' and a sinuosity ratio of 1.33, moderate values in comparison to the RSU's in the high problem areas between Ingleside and Williamson.

This study recognizes the importance of tonnage, axle loads, speeds, and varying standards of maintenance as major factors in rail maintenance. However, in this study, those

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[96] Steven G. Obenchain, Roadmaster, Norfolk Southern Corporation, interview by author, 15 November 1989, Christiansburg, Va.

factors are assumed to be constant and the emphasis is placed on the contribution of climate and terrain as environmental factors to rail maintenance of way problems.

Vegetation Control

On the Norfolk Southern system, with a longer growing season than northern railroads, the primary noxious weeds are Bull thistle (*Cirsium vulgare*), Canadian thistle (*Cirsium arvense*), Johnson grass (*Sorghum halatense*), and Kudzu (*Pueraria lobata*). Brush cutting is a separate function and involves the use of "on and off" track mechanical, rotary cutters to clear brush as much as 35 feet from the track centerline and especially around signal poles, signs, and maintenance sheds along the right of way. Laws usually require that vegetation be cleared within 500 feet of the approaches to any highway crossing.[97]

The distribution of vegetation control problem areas along the study route is concentrated in the Appalachian Plateau in the Tug Fork Basin, from Bluestone (35) through the Williamson (44) RSU's--a distance of 100 miles. The Wharncliffe (41) and Vulcan (42) RSU's in this section have the highest number of problem areas with six each. In the remaining 440 miles of the study route, there are only four additional vegetation control problem areas--one each in the

[97]E. Paul Hatten, Assistant Engineer of Maintenance of Way, Norfolk Southern Corporation, interview by author, 7 June 1989, Atlanta, Ga.

Long Island (19) RSU along the Roanoke River, and along the Ohio River in the Ironton (52), Haverhill (53) and Sciotoville (54) RSU's.

Vegetation control, to include brush cutting, is not done by Norfolk Southern maintenance personnel, but rather by commercial firms under contract to the company. The complexity of the vegetation control problem, to include compliance with state and federal environmental regulations, the expense of operating and maintaining "high-tech" herbicide spray and brush-cutting machinery, and the fact that the company used by Norfolk Southern is non-union, has led Norfolk Southern to contract for the services.[98] These companies are similar to the "custom combiners" of the midwest as they follow the growing season patterns of the vegetation with their herbicide spray and brush-cutting machines. The significance of the employment of commercial firms to this study is the fact that contractual obligations dictate that vegetation control is accomplished in an acceptable fashion. The author traveled over the 560 miles of the route on different occasions and never observed a problem with vegetation growing in or along the roadbed. Although the effectiveness of herbicides is affected by temperature, humidity, and rainfall, the application methods used by the contractors along the study route are effective. However, the effectiveness of brush cutting and vegetation

[98]Hatten, interview by author, 7 June 1989.

clearance around signal poles, signs, and maintenance sheds along the right of way did vary. As shown in Table 8, page 123, a problem area is indicated clearly in the Tug Fork Basin. This spatial concentration is due to two factors: (1) today, signal and communication lines are buried in the Virginia Division but remain above ground and along the right of way in the Pocahontas Division (Bluefield to Portsmouth), and (2) the signal and communication lines located on the upslope side of the roadway protrude into the vegetation growing on the slope, creating a unique problem. Illustrations of this problem can be seen in photographs of the route in the Pocahontas Division (see Figure 13, page 55) and in the Virginia Division before the lines were buried (see Figure 11, page 48). "Hy-rail" mechanical brush cutters are limited in their reach up the slopes, and the employment of chemical brush control risks peripheral damage to valuable vegetation on the slopes due to drift effects.

Climate does not have an appreciable effect on vegetation control along this route because of the effectiveness of the herbicides and their application systems. This is not always the case, however, as Ayres suggests in his study of the Denver and Rio Grande Western Railroad. On that rail line in an inherently drier climate, weeds generally do not grow above 8,300 feet (MSL), thus there is no requirement for herbicide spraying on much of that line.[99] Along this study route, however, terrain, in the form of steep, side slopes along the right of way in the Pocahontas Division, does present a problem for brush control.

Washouts and Floods

From Table 8, page 123, the RSU's with washout and flood problems occur primarily between the Davy (38) and Cyrus (50) RSU's in the Tug Fork Basin of West Virginia and Kentucky. A few isolated problem areas also occur as the route crosses the swampy area of the Blackwater River (Ivor [4] RSU), and as the route follows the Roanoke River and Goose Creek (Leesville [21], Huddleston [22], Hardy [24], and Salem [25] RSU's), the New River (Narrows [31] and Glen Lyn [32] RSU's), and along the Ohio River (Kenova [51], Ironton [52], and Haverhill [53] RSU's).

Flooding in the Tug Fork Basin is a major problem and has had a significant effect in the past on the rail line. The study route descends from the Elkhorn Tunnel near Bluefield and remains in the Tug Fork Basin for 157 miles until it joins the Ohio River at Kenova. The Tug Fork Basin encompasses nearly 1,560 square miles in the Appalachian Plateau physiographic province in southwestern West Virginia, eastern Kentucky, and western Virginia (portions

[99]Ayres, "An Investigation of the Geography of Maintenance Costs on the Denver and Rio Grande Western Railroad," 10.

of Buchanan and Tazewell counties). The terrain in the area is characterized by narrow, V-shaped drainageways bordered by steeply rising mountains and hills. Elevation for the basin ranges from 530 feet (MSL) at the mouth of the Big Sandy River on the Ohio River to 3,400 feet (MSL) on Flat Top Mountain at the intersection of the McDowell, Mercer, and Wyoming county lines. The basin has an average basin slope of 49%, while the average side slope along the Norfolk Southern rail line in the basin is 56%. The stream gradient is steepest in the upper reaches: 75 feet per mile on Elkhorn Creek at Elkhorn and 21 feet per mile on the Tug Fork River at Panther, but flattens near the mouth with only 3 feet per mile at Kermit (see Figure 27). The flood plains along the Tug Fork in which the rail line is situated vary in width from 300 feet at Welch to 1,800 feet at Williamson. Valley bottoms are only slightly wider than the stream channels in the upper reaches of the Tug Fork (see Figure 28). The extremely steep slopes, steep stream gradients, and narrow flood plains contribute to the high flooding potential along the route.[100]

The Tug Fork Basin has a continental climate with abundant precipitation; mean annual precipitation ranges

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[100]John S. Bader et al., *Water Resources of the Tug Fork of Big Sandy River Basin West Virginia, Kentucky, and Virginia and Twelvepole Creek Basin, West Virginia*, West Virginia Geological and Economic Survey River Bulletin 8 (Morgantown, W.Va.: West Virginia Geological and Economic Survey, 1989), 4-9.

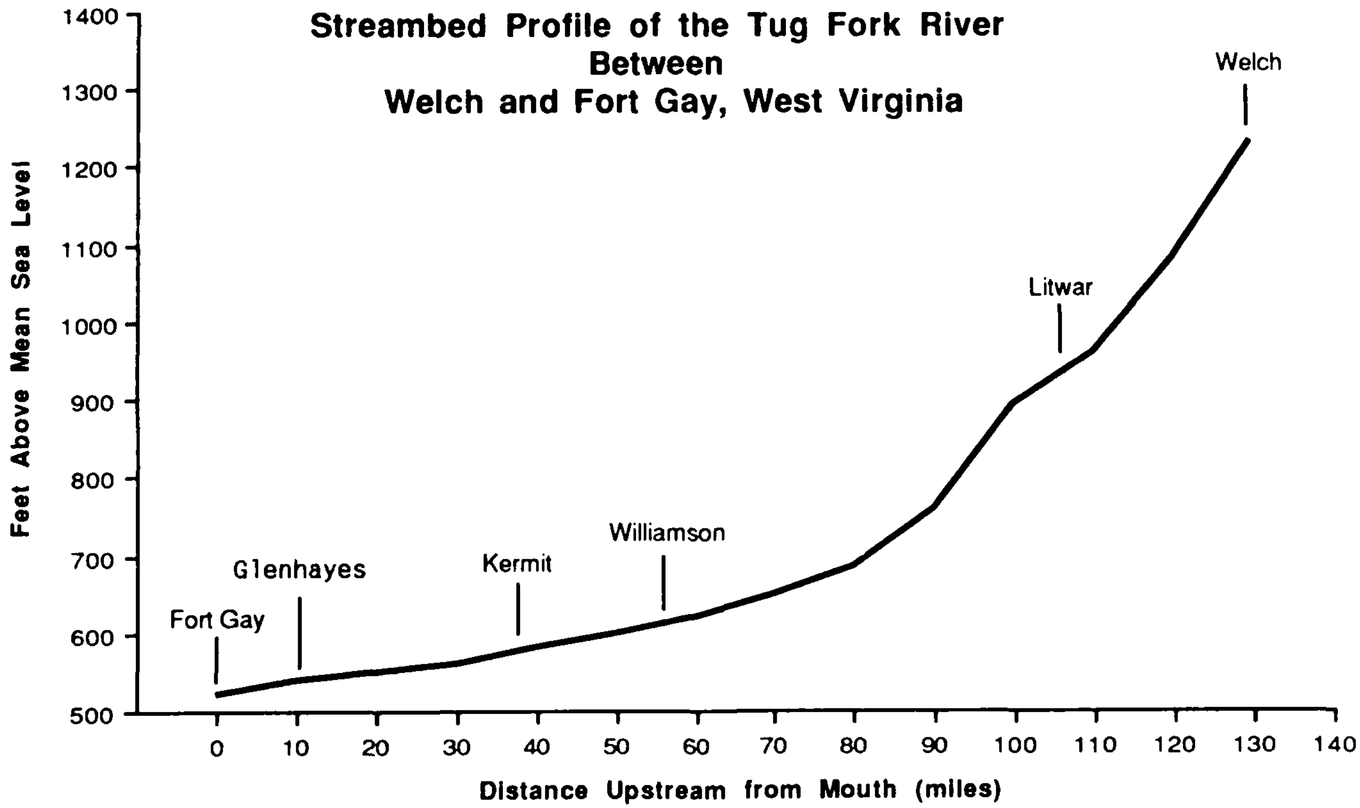
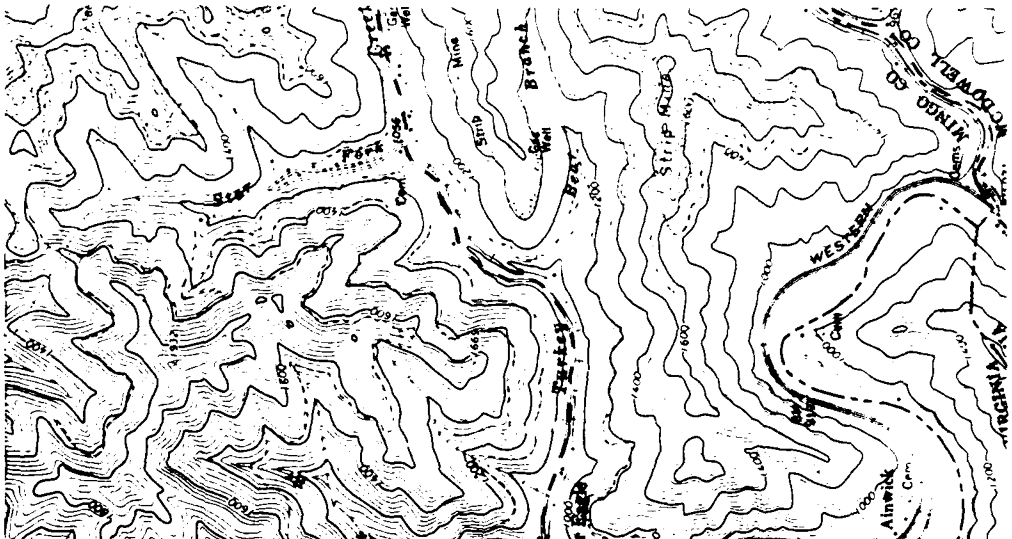


Figure 27. Streambed Profile of the Tug Fork River Between Welch and Fort Gay, W.Va.

Figure 28. Norfolk Southern Railway Along the Tug Fork River at Wharncliffe, W.Va.

A section of the study route taken from a 7.5 minute USGS topographic quadrangle.

Scale: 1:24,000.



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from 44 inches at Iaeger and 43 inches at Williamson to 40 inches at Gary and Huntington. Mean annual snowfall ranges from 27 inches at Huntington to 20 inches at Gary. Flash flooding, a significant occurrence during the summer months, is caused largely by severe thunderstorms that drop intense rainfall on small drainage basins with steep slopes. Rainfall amounts in excess of five inches in a 24-hour period have occurred in the Tug Fork Basin. Gary and Huntington average eight days per year of precipitation greater than one inch and 51 thunderstorms.

Land use and its effect on surface cover also contribute to the washout and flood problems for the Norfolk Southern. Historically, land use in the basin has changed from small homesteads and gardens to the extensive coal mining operations of today. From 1880 to 1920, logging was a major industry as timber was required for the construction of dwellings and buildings in coal mining towns, crossties for railroads, and props to support the roofs of deep coal mines. Coal mining has been a major activity in the Tug Fork Basin since the late 1800's. Prior to World War II, mining was mostly conducted by deep, underground methods. Since that time, however, the use of surface mining techniques has accelerated because of improvements in mining machinery and the economic and safety advantages of surface rather than deep mining.[101] Extensive surface mining disrupts and reshapes the original surface landscape by destroying the natural vegetation and by re-orienting surface drainage. Overall, these effects increase surface runoff, thus exacerbating the flooding potential as well as creating a siltation problem for streams.

Major floods have occurred in the Tug Fork Basin in 1875, 1918, 1926, 1955, 1957, 1958, 1963, 1967, 1972, 1974, and 1977. The maximum observed discharge in the basin is 104,000 cubic feet per second. This flow occurred on the Tug Fork River during the April 1977 flood at the Kermit USGS gaging station (#03214000). The recurrence interval for this discharge (average number of years during which a given discharge is equalled or exceeded) at Kermit was in excess of 100 years.[102] This major flood caused severe damage throughout the Tug Fork Basin, as towns from Welch to Fort Gay were under 20 to 25 feet of water. The floodwaters at Williamson, which is surrounded by a floodwall that protects the main business district (but not the major Norfolk Southern railyard) up to a flood stage of 44 feet,

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[101] James A. Barlow, *Coal and Coal Mining in West Virginia*, Coal Geology Bulletin No. 2 (Morgantown, W.Va.: West Virginia Geological and Economic Survey, 1974), 43-44.

[102] Arthur G. Scott, *An Interim Report on the Investigation of Flooding in the Tug Fork Basin of Kentucky, Virginia, and West Virginia*, U.S. Geological Survey Open File Report 80-1188 (Washington, D.C.: Government Printing Office, 1980), 8-10.

reached a peak stage of 52.56 feet.[103] Consequently, the rail line between the Davy (38) and Kermit (46) RSU's was inundated, with the highest floodwaters 10 to 20 feet over the tracks in the Matewan (43) and Williamson (44) RSU's.[104]

A second area of washout and flood problems occurs in the Leesville (21) and Huddleston (22) RSU's along Goose Creek, a tributary of the Roanoke River. Specifically, the area of concern is between Mileposts V-208 and V-212, two miles west of the Campbell-Bedford county line (see Figure 29). Roadmaster Brown reported several incidents of high water and washouts around the two bridges over Goose Creek in 1988 and 1989 and floodwaters over the tracks in September of 1987. He also observed that the Goose Creek channel appeared to be cutting into the trackside embankment at a higher rate over the last few years.[105] A USGS gaging station (#02059500) is located on Goose Creek 3.5 miles

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[103]Gerald S. Runner, *Flood of April 1977 in the Appalachian Region of Kentucky, Tennessee, Virginia, and West Virginia*, U.S. Geological Survey Professional Paper 1098 (Washington, D.C.: Government Printing Office, 1980), 31.

[104]Where the tracks are located in proximity to streams, the Norfolk Southern Track Charts indicate on the profile view the elevation and date of the highest water levels. For example, using the Track Charts, one can determine that on 27 January 1937, the Norfolk and Western tracks at Ironton, Ohio (milepost N-579.5), were inundated by floodwaters reaching an elevation of 553.51 feet MSL; fortunately, the town of Ironton was spared since the floodwaters did not exceed the floodwall which is at an elevation of 560 feet.

[105]Brown, interview, 21 June 1989.

Figure 29. Main Line Track Along the North Bank of Goose Creek Near Huddleston, Va.

northwest of Huddleston (Milepost V-214.8). The average annual peak discharge over 61 years for this station is 7,976 cubic feet per second. The average annual peak discharge from 1960 to 1969 was 3,737 cubic feet per second; from 1970 to 1979, it was 9,334 cubic feet per second; and from 1980 to 1988, the average annual peak discharge was 11,647 cubic feet per second. The climatic data for this area of Bedford County represents a 30-year normal period and does not indicate any significant changes in precipitation. One possible explanation for the higher discharge rates is the effect on runoff in the drainage basin of increased "clear-cutting" by commercial timbering in Bedford County.

The problems in the Hardy (24) and Salem (25) RSU's reflect the occasional flooding of the Roanoke River along the main line tracks as they pass around the south side of the city of Roanoke. Using data from the USGS gaging station at Roanoke (#02055000), the tracks in this area have been flooded three times since 1970, the most recent occurrence being the devastating Mid-Atlantic flooding in 1985. This flooding was caused by extremely heavy thunderstorms that developed from an intense, slow-moving low pressure area and dropped 6.6 inches of rain in the Roanoke area on 4 November. The peak discharge at this

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[106] Floyd L. Snow, "Table of Annual Peak Stages and Discharge for Goose Creek Near Huddleston, Va." (Charlottesville, Va.: USGS Water Resources Division, 1990).

gaging station during that event was 32,300 cubic feet per second, exceeding the 100-year recurrence interval.[107]

Washouts and floods can present serious problems to railroad operations. Washouts can lead directly to train derailments with resulting loss of life and property. Repairs to the roadway damaged by floods may delay traffic for weeks. Rapidly rising flood waters in narrow valleys, such as the Tug Fork, may isolate trains. Diesel-electric and electric locomotives can run through water over the track but are limited to a depth of only three inches to keep moisture out of the traction motors.[108] Norfolk Southern roadmasters indicated that washout and flooding problems existed in 20 of the 54 RSU's in the study. While not a frequent problem, washouts and floods represent a potential for serious maintenance and operational problems on the route between Norfolk and Portsmouth.

Snow and Ice

Although snow and ice can create very serious maintenance problems along a rail line, especially in mountainous areas, that expectation was not met in this study. The consensus of Assistant Division Engineers

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[107] Joseph B. Lescinsky, *Flood of November 1985 in West Virginia, Pennsylvania, Maryland, and Virginia*, U.S. Geological Survey Open File Report 486 (Washington, D.C.: Government Printing Office, 1987), 22.

[108] Hay, "Effects of Weather on Railroad Operations," 27.

Meadows and McCracken and the 10 roadmasters was that snow and ice are not major problems but an "expensive aggravation." Nevertheless, the Norfolk Southern maintains a fleet of snow removal equipment, employs electric- and gas-powered switch heaters, and has contingency plans to reroute traffic in the event that sections of the main line are blocked through snow and ice problems. Cold winter temperatures and substantial winter precipitation can produce ice and snow in all sections of the route. The mean annual snowfall amounts range from 7.6 inches at Norfolk to 33.7 inches at Bluefield, and extreme maximum monthly snowfall amounts range from 17.0 inches at Gary to 49.2 inches at Bluefield. An interesting note on the variability of climate is that during the winter of 1979-80, Norfolk, a coastal city of mild winters and ocean breezes, received 41.9 inches of snow!

Many factors affect the impact of winter storms on railroad maintenance operations. These include: (1) temperature, (2) wind (wind-chill effect and snow drifting), (3) rate and type of precipitation (snow, sleet, or freezing rain), (4) total accumulation, and (5) cloud cover (effect on insolation).[109] Climate-related parameters alone, however, cannot explain the spatial variation of snow and ice problems in the study area; certain terrain-related

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[109]James F. Kelly, "Winter Maintenance: A Four-Season Job," *American City and County*, August 1978, 73.

factors are more directly important. The influence of side slopes and narrow cuts on the length of time that snow and ice remain on the roadway, a condition known as snow and ice persistence, is an example of such a terrain factor. Snowfall persistence is affected not so much by the depth of the initial accumulation, since a lowering of the snow depth could result from an increase in snow density due to aging, compaction, or refreezing, but rather to the effects of solar radiation and the rates of surface and subsurface melting of snow. Of these factors, the input of direct-beam, shortwave solar radiation is the most important. The intensity of this type of radiation is dependent on the angle at which it strikes the surface. Thus, the radiation varies in intensity with the slope and azimuth angles presented by terrain. In the Northern Hemisphere at 40° N latitude, at the time of the winter solstice (22 December), north-facing slopes greater than 58% (26.5°) receive no direct-beam solar radiation (are in shadow), while south-facing slopes at any angle are in a favorable position.[110] The latitudinal amplitude of the study route varies from N 36°45' at Suffolk to N 38°45' at Portsmouth.

A second terrain-related factor affecting the variability of snow and ice problems is the buildup and persistence of ice in many of the 34 tunnels along the route. Moisture is abundant in most of the tunnels, and ice

[110]Oke, *Boundary Layer Climates*, 76, 147-150.

that forms in tunnels receives no direct-beam insolation and persists for an inordinate amount of time. Assistant Division Engineer McCracken noted that, occasionally, the ice buildup is so severe in the Pepper Tunnel (Ellett [27] RSU) and the Goodview Tunnel (Hardy [24] RSU), that the rail line is shut down until the ice is chipped away.[111] This action is necessary to prevent derailments.

The point of this discussion is that, potentially, any RSU that has trackage located along north-facing slopes greater than 58%, in areas of narrow cuts, and through "wet" tunnels, may encounter snow and ice maintenance of way problems during the winter months.

In Table 8, page 124, snow and ice problems are only indicated in 16 RSU's; all but two of these are in the Appalachian Plateau, with a maximum of only two problems in any RSU. The concentration of snow and ice problems in the 50 miles from the Ingleside (33) through the Davy (38) RSU's reflects the location of the route: (1) along north- and northeast-facing slopes averaging 59%, (2) through 1.2 miles of cuts, (3) through 13 tunnels, and (4) in an area that annually averages 27 inches of snow and 117 days with temperatures below 32°F. Roadmaster Keys, responsible for the final 50 miles of the route from the Fort Gay (49) through the Sciotoville (54) RSU's, indicated that while

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[111]Jeff A. McCracken, Assistant Division Engineer, Virginia Division, Norfolk Southern Corporation, interview by author, 3 January 1990, Roanoke, Va.

there were some problems with frost heaves along his track, he had no major problems with snowfall.[112] Fine-grained sands, silts, and clays retain moisture and promote frost heaving; also, repeated freeze/thaw cycles increase the moisture content and the severity of frost heaving. The route in Roadmaster Keys' area proceeds along terraces and flood plains of the Big Sandy and Ohio rivers on the Huntington and Elkinsville silt-loam soils with high water tables and in an area that averages 80 freeze/thaw cycles per year, a combination of environmental factors that favors frost heaving.

Again, maintenance problems involving snow and ice are generally confined to the portion of the route in the Appalachian Plateau where terrain and climate provide favorable environmental conditions.

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[112]Ted R. Keys, Roadmaster, Norfolk Southern Corporation, interview by author, 19 July 1989, Portsmouth, Ohio.

CHAPTER VI

DEVELOPMENT OF RAILROAD MAINTENANCE ZONES

In this chapter, the actual distribution of the maintenance of way problems along the route, as determined by the author's field inspections and input from the roadmasters' track charts will be compared to Railroad Maintenance Factors (RMF's). Those Railroad Study Units (RSU's) with high maintenance factors would be expected to have the higher number of maintenance problem areas; conversely, those RSU's with low factors would not be expected to have many problems with maintenance of way, at least not in terms of the effects of climate and terrain. Also in this chapter, the concept of Railroad Maintenance Zones will be introduced as a geographical construct that integrates the relationships of climate and terrain to maintenance of way on particular segments of the route.

Development and Evaluation of Railroad Maintenance Factors

To further the comparison of maintenance of way between RSU's, each RSU was assigned a Railroad Maintenance Factor, or RMF (see Table 9). The RMF's are based on the terrain analysis conducted along the study route and include the 10 previously selected climate and terrain variables (see page 121). The values for each variable were adjusted to a dimensionless scale of 0 to 1.0, by dividing each value by

TABLE 9

RAILROAD MAINTENANCE FACTORS (RMF'S)

Segment	RSU No.	LCLRLF[1]	SSLOPE	CUTFIL	FLOOD	SINRAT	TCURVE	FTCYCL	DPG0.1	LNDSL	SOILR	RMF	RMC
Yadkin	1	.01	0	.23	0	0	0	.44	.87	0	1.00	2.55	VL
Suffolk	2	.03	0	.09	0	.01	0	.64	.82	0	1.00	2.59	VL
Windsor	3	.03	0	.45	0	0	.01	.64	.82	0	.75	2.70	VL
Ivor	4	.03	0	.41	.80	0	.01	.64	.82	0	.75	3.46	VL
Wakefield	5	.03	0	.68	0	0	.01	.62	.82	0	.75	2.91	VL
Waverly	6	.03	0	.55	0	0	0	.62	.82	0	.75	2.77	VL
New Bohemia	7	.04	.01	.75	0	.04	.03	.62	.82	0	.75	3.06	VL
SW Petersburg	8	.05	.04	.90	0	.04	.01	.62	.82	.70	1.00	4.18	L
Church Road	9	.07	.05	.69	0	.05	.04	.65	.77	0	1.00	3.32	VL
Hebron	10	.08	.01	.68	0	.04	.04	.65	.77	0	1.00	3.27	VL
Blackstone	11	.08	0	.14	0	.21	.08	.65	.77	0	1.00	2.93	VL
Crewe	12	.08	0	.18	0	.04	.10	.65	.77	0	1.00	2.82	VL
Burkeville	13	.10	.04	.91	0	.04	.01	.92	.83	0	1.00	3.85	L
Virso	14	.09	.03	1.00	0	.18	.02	.92	.83	0	1.00	4.07	L
Abilene	15	.08	.05	.82	0	.36	.12	.92	.83	0	1.00	4.18	L
Phenix	16	.09	.10	.99	0	.06	.14	.92	.83	0	1.00	4.13	L
Aspen	17	.11	.09	.77	0	.14	.12	.73	.86	0	1.00	3.82	L
Brookneal	18	.11	.33	.55	.80	.14	.17	.73	.86	.70	1.00	5.39	M
Long Island	19	.15	.23	.42	.80	.38	.20	.73	.86	.70	1.00	5.47	M
Altavista	20	.18	.53	.36	1.00	.85	.30	.73	.86	.70	1.00	6.51	H
Leesville	21	.18	.82	.27	.80	.12	.18	.74	.82	.70	1.00	5.63	M
Huddleston	22	.17	.27	.48	1.00	.15	.26	.74	.82	1.00	1.00	5.89	H
Moneta	23	.20	.34	.55	0	.01	.26	.74	.82	1.00	1.00	4.92	M
Hardy	24	.42	.67	.54	0	.13	.32	.72	.87	1.00	1.00	5.67	M
Salem	25	.49	.25	.12	1.00	.21	.14	.72	.87	.20	1.00	5.00	M
Lafayette	26	.69	.42	.18	1.00	.17	.25	.72	.87	.20	.75	5.25	M

TABLE 9 (continued)

Segment	RSU No.	LCLRLF[1]	SSLOPE	CUTFIL	FLOOD	SINRAT	TCURVE	FTCYCL	DPG0.1	LNDSL	SOILR	RMF	RMC
Ellett	27	.56	.71	.26	.60	.35	.34	1.00	.90	1.00	1.00	6.72	H
Whitethorne	28	.34	.71	.20	.40	.21	.29	1.00	.90	.20	1.00	5.25	M
Eggleston	29	1.00	.66	0	.80	.50	.50	1.00	.90	.20	1.00	6.56	H
Pembroke	30	.55	.95	.03	.60	.70	.46	1.00	.90	.20	1.00	6.39	H
Narrows	31	.87	.80	.05	1.00	.60	.39	1.00	.90	.20	1.00	6.81	VH
Glen Lyn	32	.86	1.00	0	1.00	.55	.78	1.00	.90	.20	1.00	7.29	VH
Ingleside	33	.89	.56	.14	.80	.06	.92	.83	.98	.20	.75	6.13	H
Bluefield	34	.67	.54	.06	.80	.04	.42	.83	.98	.20	.50	5.04	M
Bluestone	35	.36	.92	.06	.80	.47	1.00	.83	.98	.20	.50	6.12	H
Elkhorn	36	.55	.76	.09	1.00	.26	.39	.97	.97	1.00	.75	6.74	VH
Kimball	37	.52	.82	.02	1.00	.43	.70	.97	.97	1.00	.50	6.93	VH
Davy	38	.47	.68	.05	1.00	.37	.62	.97	.97	1.00	.50	6.63	H
Iaeger	39	.51	.66	.09	1.00	.51	.59	.97	.97	1.00	.50	6.80	VH
Panther	40	.47	.53	.02	1.00	.46	.56	.97	.97	1.00	.50	6.48	H
Wharncliffe	41	.51	.75	0	.80	.72	.67	.85	1.00	1.00	.50	6.80	VH
Vulcan	42	.52	.94	0	1.00	1.00	.96	.85	1.00	1.00	.50	7.77	VH
Matewan	43	.60	.89	0	1.00	.43	.48	.85	1.00	1.00	.50	6.75	VH
Williamson	44	.55	.99	.02	1.00	.29	.40	.85	1.00	1.00	.50	6.60	H
Naugatuck	45	.47	.65	.15	1.00	.57	.38	.85	1.00	1.00	.50	6.57	H
Kermit	46	.36	.38	.09	1.00	.15	.32	.85	1.00	1.00	.50	5.85	H
Webb	47	.32	.71	.15	1.00	.80	.34	.67	.94	1.00	.50	6.43	H
Glenhayes	48	.27	.53	.37	.80	.01	.24	.67	.94	1.00	.50	5.33	M
Fort Gay	49	.26	.54	.32	.80	.44	.17	.67	.94	1.00	.75	5.89	H
Cyrus	50	.23	.52	.27	.60	.19	.12	.67	.94	1.00	.75	5.29	M
Kenova	51	.17	.49	.11	1.00	.21	.29	.67	.94	.70	.75	5.33	M
Ironton	52	.16	.54	.13	1.00	.02	.19	.75	.88	.70	.75	5.12	M
Haverhill	53	.17	.73	.08	1.00	.06	.02	.75	.88	.70	1.00	5.39	M
Sciotoville	54	.18	.76	.14	1.00	.24	.08	.75	.88	.70	.75	5.48	M

[1]Abbreviations as in Table 5, page 117.

the highest value for that variable. For example, in the category of side slopes, the steepest slopes in the study, the 79% slopes near Glen Lyn, Virginia, received a factor of 1.0; the 42% slopes near Panther, West Virginia, received a factor of .53; and, the 4% slopes near Abilene, Virginia, received a factor of .05. The variables were not weighted, and the scaled values represented a means to indicate relative importance. Each of the 54 RSU's received a total score, or Railroad Maintenance Factor (RMF), between 0 and 10. The RSU's were then classified as to their level of maintenance problems according to the RMF intervals shown in Table 10. From the author's experience, three to five categories or levels of maintenance are normally used in maintenance management. For this study, five intervals were selected to provide sufficient variability along the study route. The breakpoints for the intervals represent the division of the range of RMF's into five equal

TABLE 10

RAILROAD MAINTENANCE CLASSES (RMC's)

Railroad Maintenance Factor Intervals	Railroad Maintenance Classes
1. 2.55 - 3.59	Very Low (VL)
2. 3.60 - 4.64	Low (L)
3. 4.65 - 5.68	Medium (M)
4. 5.69 - 6.73	High (H)
5. 6.74 - 7.77	Very High (VH)

intervals. By classifying each 10-mile RSU according to its RMF and aggregating similar classes, a geographical pattern of Railroad Maintenance Zones (RMZ's) emerges.

To test the concept that relationships exist between climate and terrain and maintenance of way, the actual distribution of maintenance problems, as determined by the author's field inspections and input from the roadmasters' track charts, will be compared with the Railroad Maintenance Factors (see Table 9). It is hypothesized that: (1) the RMZ's will be related to variations in climate and terrain and approximate the physical subdivisions of the study area, (2) the RMZ's will reflect the actual maintenance of way problem areas along the route, and (3) the RMZ's will serve as maintenance management indicators to predict long-term maintenance of way problem areas.

According to Table 9, the RSU with the highest rated RMF is Vulcan (42), with an RMF of 7.77, and the lowest rated RSU is Yadkin (1), with an RMF of 2.55. In reality, Vulcan is the RSU with the second highest number of maintenance problem areas (25) and Yadkin is the second lowest RSU with only two problem areas. The route through the Vulcan RSU is situated in the winding, narrow, and steep-sided Tug Fork River Valley of the Appalachian Plateau. As a result, Vulcan receives maximum values (1.0) for landslide potential, days with 0.1 inch precipitation, flood potential, and sinuosity ratio; near-maximum values for total curvature (.96) and side slopes (.94); and a high value (.85) for freeze/thaw cycles. Most RSU's in this section of the Tug Fork Basin would have similar terrain and climatic patterns, hence similar RMF's; the discriminators for Vulcan are the high values for sinuosity ratio and total curvature. Vulcan has the highest sinuosity ratio of any RSU in the study, 1.94. To put this ratio in perspective, as one travels this Norfolk Southern rail line toward Portsmouth and enters the Vulcan RSU, 1.2 air-miles east of Devon, one continues along the route and exits the RSU .2 mile south of the Grapevine Creek bridge 10 track-miles later, but only 5.1 miles closer to Portsmouth. Additionally, the Vulcan RSU has the second highest total curvature in the study, with 378°30'. The route encounters three major curves in the Vulcan RSU: (1) Looney's Curve at Milepost N-445.1, maximum curvature of 11°56', (2) Cedar Curve at Milepost N-450, maximum curvature of 13°08', and (3) Delorme Curve at Milepost N-453.6, maximum curvature of 12°12'.[113] Of the 10 RSU's with the highest RMF's: Vulcan (42), Glen Lynn (32), Kimball (37), Narrows (31), Iaeger (39), Wharncliffe (41), Matewan (43), Elkhorn (36), Ellett (27), and Davy (38), seven are located in the upper reaches

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[113]Traditionally, tight curves on rail lines are named; perhaps the most famous one in the eastern United States is Horseshoe Curve west of Altoona, Pennsylvania, on the old Pennsylvania Railroad. This famous curve, now maintained by CONRAIL, is not as tight as the Cedar Curve found in the Vulcan RSU.

of the Tug Fork Basin in the Appalachian Plateau, two are located along the New River Valley in a transitional area between the Ridge and Valley and the Appalachian Plateau, and one RSU is located in the Ridge and Valley on the divide between the New and Roanoke river basins. More importantly, five of these 10 RSU's are also ranked in the 10 highest numbers of actual maintenance problem areas, and only Narrows (31) is not among the top 15. In other words, the Davy RSU is the tenth rated RMF with 6.63 but has the fifth highest number of problem areas with 17.

The study route begins at the western yard limit of the Norfolk Terminal and proceeds for 10 miles in the Yadkin RSU across the northern end of the Great Dismal Swamp. In terms of Railroad Maintenance Factors, Yadkin receives a maximum value (1.0) for the type of soils found in the swamp and a high value (.87) for daily precipitation; otherwise, Yadkin receives low values to include zero values for side slopes, flood potential, sinuosity ratio, and total curvature. The route through the Yadkin RSU is a tangent and level rail line on the Coastal Plain built on a roadbed with good drainage that has withstood the effects of climate and tonnage for 130 years. Roadmaster Steele reported only two areas of maintenance problems in this RSU, and those were areas of "muddy track."[114] Of the 10 RSU's with the lowest RMF's: Yadkin (1), Suffolk (2), Windsor (3), Waverly (6),

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[114]Steele, interview by author, 6 July 1989.

Crewe (12), Wakefield (5), Blackstone (11), New Bohemia (7), Hebron (10), and Church Road (9), six are located in the Coastal Plain and the remainder in the Piedmont. In fact, these 10 lowest rated RSU's present a 120-mile, east to west continuum from the starting point at Norfolk through the Crewe RSU, with the exceptions being the Ivor (4) and SW Petersburg (8) RSU's. Additionally, seven of these 10 RSU's are also ranked among the 10 lowest RSU's for actual maintenance problem areas.

The strength of the association between the RSU rank ordered series of Railroad Maintenance Factors and actual maintenance problem areas was tested using Spearman's rank correlation coefficient (r_r). Using this non-parametric technique, the RSU's were ranked from 1 to 54 according to their RMF's and from 1 to 54 according to their total number of maintenance problem areas. Average rankings were substituted for tied ranks where necessary. Using the computational formula:[115]

$$r_r = 1 - \frac{6 \Sigma d^2}{n(n^2-1)}$$

where, d = difference between the RSU ranks for the paired observations
n = number of paired observations

substituting, $r_r = 1 - \frac{40162.5}{157410} = .745$

[115] John Silk, *Statistical Concepts in Geography* (Boston: George Allen and Unwin, 1979), 201-203.

Using the Student t-distribution and a calculated t-statistic of 8.05, the computed rank correlation coefficient is significant at the 1% level. The results of the computation suggest a moderately strong, positive association between the Railroad Maintenance Factors and the maintenance problem area rankings. This is significant, because the RMF's are based solely on variables that reflect the climate and terrain of the study area rather than variables concerning tonnage, frequency, and the speed of the Norfolk Southern trains, factors which are usually attributed to be major influences on maintenance of way. The results of the analysis suggest the importance of evaluating climate and terrain when considering maintenance-of-way problems and their associated costs.

A second iteration of the Spearman's rank correlation coefficient was calculated using only the eight terrain variables; the climatic variables for annual number of freeze/thaw cycles and days with precipitation ≥ 0.1 inch were eliminated. Thus, the RSU's were re-ranked according to their revised RMF's and compared with the rankings for the number of maintenance problem areas. The results of the calculation are as follows:

$$r_r = 1 - \frac{42646.5}{157410} = .729$$

Using the Student t-distribution and a calculated t-statistic of 7.67, the computed rank correlation coefficient is significant at the 1% level. The results of the computation with only terrain-related variables also suggest a strong, positive association between the RMF's and maintenance problem area rankings. For this particular study route between Norfolk and Portsmouth, the climatic variables are not so distinctly different as to be major factors in the analysis. Rather, the influence of climate is seen through geomorphic (terrain-related) processes such as floods, washouts, and landslides. It should be noted that the variables used in this study may or may not be appropriate for similar studies in other locations.

Comparison of Railroad Maintenance Zones to Physical Subdivisions

To further the analysis of the relationships of climate and terrain to maintenance of way, the RSU's were classified into Railroad Maintenance Classes (RMC's) according to their maintenance factors (see Table 10, page 173). The RSU's, when aggregated by class into Railroad Maintenance Zones (RMZ's), represent the imposition of a geographical construct on the study route. Through the aggregation of similar RMC's, a pattern of maintenance difficulty can be developed. For example, the 120 miles of the route from the Yadkin (1) RSU through the Crewe (12) RSU are classified as a Very Low RMZ, the single exception being the SW Petersburg (8) RSU which has an unusually high value (.70) for landslide potential. In fact, this is the only RSU between Yadkin and Brookneal (18) with any value for landslide potential.

Initially, the RMZ's were to be compared with Fenneman's (1938) physiographic divisions as used up to this point in the description of the terrain along the route. However, because the definition of areal physiographic units is both subjective and highly geological and lacks quantifiable interpretation, and because terrain features may be examined at a variety of scales, a stronger relationship was found by comparing the RMZ's with the physical subdivisicns developed by Hammond.[116] The juxtaposition of the study route with Hammond's classes of land-surface form provides more categories for the area (eight, compared with five for Fenneman) and, therefore, better discrimination. Hammond's classification, which describes and quantifies the form of the land surface in terms of slope, local relief, and profile characteristics is perhaps better suited for an analysis of a surface transportation system such as the railroads.

Using Hammond's classification of land-surface form, the Very Low RMZ is located partially in the Gulf-Atlantic Coastal Flats for 70 miles of the route, an area of flat plains with local relief less than 100 feet, and, for 50

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[116] Edwin H. Hammond, "Classes of Land-Surface Form in the Forty-Eight States, U.S.A.," Map supplement no. 4, *Annals of the Association of American Geographers* 54 (March 1964).

miles in the eastern half of the Gulf-Atlantic Rolling Plain, an area characterized by irregular plains, 50 to 80% of the area gently sloping with local relief between 100 and 300 feet and 50 to 75% of the gentle slopes on uplands.

The next five RSU's, Burkeville (13) through Aspen (17), aggregate to form the Low RMZ. This 50-mile section of the route extends from Crewe to the Roanoke River Valley at Brookneal in the western half of the Gulf-Atlantic Rolling Plain. Clearly, one could further aggregate the Very Low into the Low RMZ to form a 170-mile continuous zone of low maintenance requirement in terrain characterized by flat or irregular plains with 50 to 80% of the area gently sloping, local relief less than 300 feet, and 50 to 75% of gentle slopes on uplands.

From the Brookneal (18) RSU through the Lafayette (26) RSU, the RMF's aggregate into the Medium RMZ. The Altavista (20) and Huddleston (22) RSU's are outliers primarily due to: (1) maximum values (1.0) for flood potential for both RSU's, (2) Altavista's high value (.85) for sinuosity ratio for the route along the Roanoke River, and (3) Huddleston's maximum value for landslide potential along Goose Creek. This Medium RMZ occupies a transitional zone from the inner part of the Gulf-Atlantic Rolling Plain through the Blue Ridge at Roanoke and into the Great Valley in an area of plains with high hills, 50 to 80% of the area gently sloping, local relief between 500 and 1,000 feet, and greater than 75% of the gentle slope in lowlands.

The RSU's from Ellett (27) through Bluestone (35) aggregate into a High RMZ. This is somewhat of a mixed zone, as the Whitethorne (28) and Bluefield (34) RSU's are Medium RMZ's and Narrows (31) and Glen Lyn (32) are Very High RMZ's. The discriminators that place Narrows and Glen Lyn in the very high classification are the flood potential for Narrows along the New River and the flood potential, side slopes, and total curvature for Glen Lyn. This High RMZ traverses through the Appalachian Ridges along the New and East rivers in an area that Hammond classifies as open low mountains with 20 to 50% of the area gently sloping, local relief between 1,000 and 3,000 feet, and greater than 75% of the gentle slopes in the lowlands.

From Elkhorn (36) through Matewan (43), the RSU's aggregate into the Very High RMZ. The Davy (38) and Panther (40) RSU's are only rated as High RMZ's, owing to lower values for local relief and side slopes. This Very High RMZ follows the winding course of the Tug Fork River in the Appalachian Highlands in an area characterized by low mountains with less than 20% of the area gently sloping and local relief between 1,000 and 3,000 feet.

From Williamson (44) to Fort Gay (49), the RSU's form a second High RMZ. The Glenhayes (48) RSU is classified as a Medium RMZ because of an unusually low sinuosity ratio value

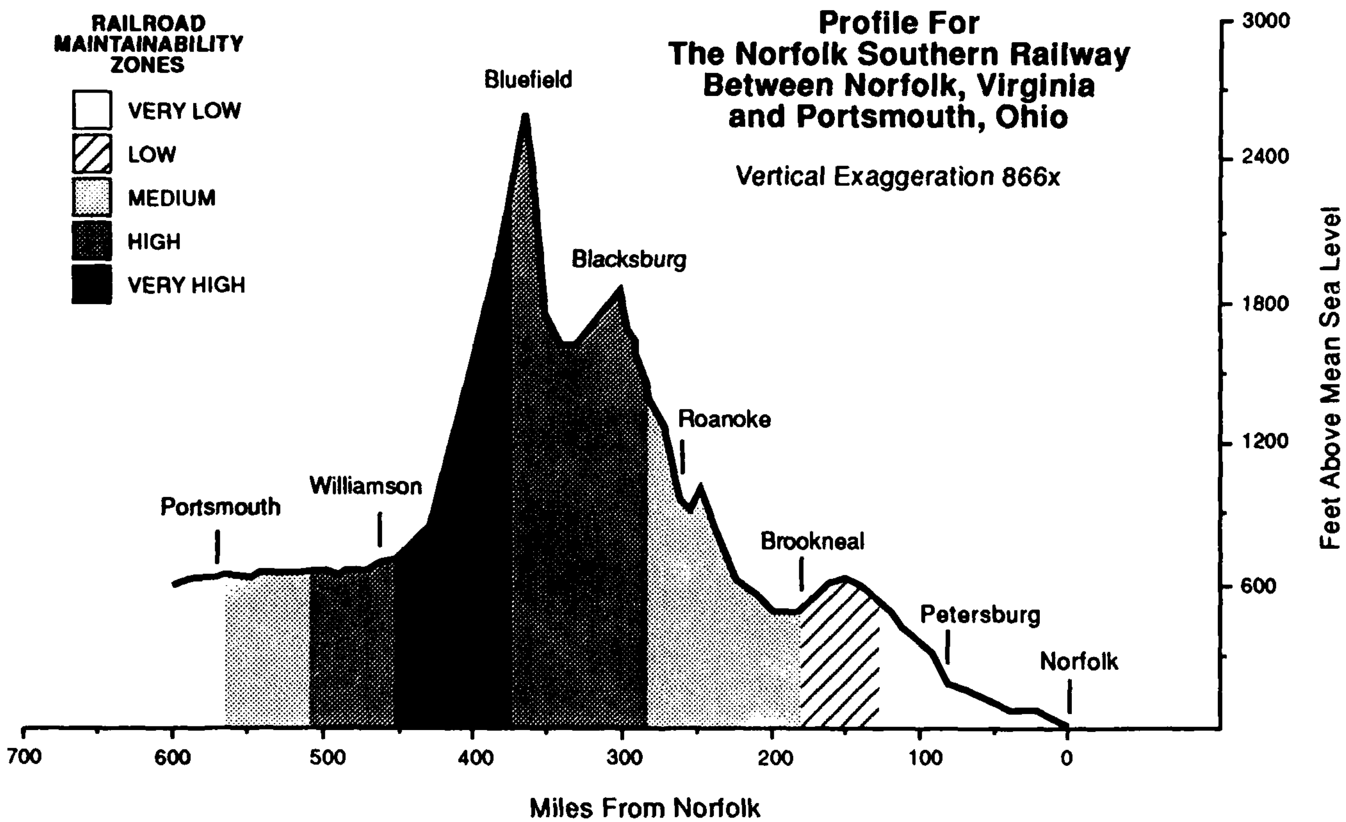
(.01) as the route follows a relatively straight section of the Tug Fork. This area of the Appalachian Highlands is characterized by high hills (contrasted with the low mountains of the Very High RMZ) with less than 20% of the area gently sloping and local relief between 500 and 1,000 feet.

The final five RSU's, Cyrus (50) through Sciotoville (54), aggregate into a second Medium RMZ as the route passes from an area of high to one of low hills as the route crosses the Ohio River at Kenova, with less than 20% of the area gently sloping and local relief between 300 and 500 feet. The distribution of the RMZ's is seen graphically in conjunction with an exaggerated profile of the study route in Figure 30.

In this chapter, the Norfolk Southern route between Norfolk and Portsmouth has been divided into maintenance zones based on factors derived from climate and terrain variables. These maintenance zones have been shown to correspond directly to the incidence of maintenance problem areas and to parallel the classes of land-surface form as described by Hammond, demonstrating that a geographical relationship exists between maintenance of way and the terrain and climate of an area. The next chapter will examine applications of this concept to geography and the railroad industry.

Figure 30. Profile (Exaggerated) of the Norfolk Southern Railway Between Norfolk, Va., and Portsmouth, Ohio, and Railroad Maintenance Zones.

An exaggerated profile of the study route for illustrative purposes with a vertical exaggeration of 866x. The Railroad Maintenance Zones (RMZ's) are also depicted on this profile.



Profile For
The Norfolk Southern Railway
Between Norfolk, Virginia
and Portsmouth, Ohio
Vertical Exaggeration 866x
RAILROAD MAINTAINABILITY ZONES
VERY LOW
LOW
MEDIUM
HIGH
VERY HIGH
Bluefield
Blacksburg
Roanoke
Brookneal
Petersburg
Norfolk
Williamson
Portsmouth
Feet Above Mean Sea Level
3000
2400
1800
1200
600
Miles From Norfolk
700
600
500
400
300
200
100
0

CHAPTER VII

APPLICATIONS OF THE STUDY TO GEOGRAPHY AND THE RAILROAD INDUSTRY

Thus far, this study has investigated the terrain and climate along a particular, 540-mile segment of the Norfolk Southern system in order to demonstrate the relationships of climate and terrain to maintenance of way. A climate and terrain analysis model was introduced, resulting in the division of the route into Railroad Maintenance Zones. This chapter will discuss the applications of this approach to geography and to the railroad industry. Additionally, military applications of this study to the strategic field of Military Geographic Information will be examined.

Location Analysis of Transportation Networks

A useful role for physical geographers, yet not fully developed in this country, is in the area of location analysis for transportation networks. As opposed to the field of economic geography, which generally considers costs without focusing on variations in climate and terrain, a physical geography approach to location analysis considers the relationships between the physical characteristics of a transportation network and the associated transportation costs. Ayres (1969) suggests that only in the civil engineering literature can one find specific information on quantifying the effects of climate and terrain on overall transportation costs. Ayres, a physical geographer, introduced a technique for measuring the difficulty of terrain for the operation of railroads.[117] The present study provides a method for quantifying the effects of climate and terrain on the maintenance of way of railroads, a significant component (17 to 20%) of a railroad's total operating costs.

Railroad networks were established in the United States for the purposes of trade. From short, connecting links between population centers, the rail network gradually developed into the extensive network of today. The selection of the routes for this network (some routes were selected over 100 years ago) has a significant bearing on the operating costs of railroads today, including maintenance costs. What were the terrain considerations used in the location analysis of the early railroad networks? The U.S. Army's *Technical Manual 5-370, Railroad Construction* suggests that railroads should be built on favorable soils, avoiding clay beds, muck, and swampy areas.

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[117]Ayres, "Measuring Difficulty of Terrain for Railroad Operation: Northeastern United States," 5-6. Railroad operating expenses have three components: maintenance of way, maintenance of equipment to include locomotives and cars, and transportation expenses to include fuel and lubricants for the operation of the trains. Ayres' study related fuel consumption to the amount of work (in terms of force exerted through a distance) required to negotiate varying terrain at reasonable speeds, with trains of reasonable weight.

Where rock cuts are required on side slopes, the bedding planes should dip away from the track to prevent rock slides. Locations of rail lines at the foot of steep slopes, cliffs, and embankments subject to frequent slides and falls are undesirable. Ridge routes are best for drainage, while river and stream crossings should be made as far upstream as possible to minimize the amount of bridging. Tunnels should be considered to pass mountain barriers, reduce the number of curves, and protect the roadway from snow and rock slides.[118]

The Army's suggestions represent an ideal situation that was seldom achieved in the railroad industry. Did the Norfolk and Western engineers follow the Army's guidelines when the route from Norfolk to Portsmouth was constructed in the 1880's and 90's? Like any railroad, they attempted to minimize grade and curvature, but the terrain along the route made this difficult, particularly in West Virginia, because of narrow ridge crests, steep side slopes, and the necessity of using narrow, winding valley routes along stream courses. In central and eastern Virginia, however, sections of the Norfolk and Western line were constructed on the crests of interfluves, providing an excellent route from the Coastal Plain into the Virginia Piedmont. Today, this

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[118] Department of the Army, *TM 5-370, Railroad Construction* (Washington, D.C.: Government Printing Office, 1970), 3-5.

section of the study route continues to have the lowest incidence of maintenance problems (see Table 8, page 123).

Valley routes generally provide the easiest gradients, the avoidance of heavy construction in rock cuts, and access to population centers. However, valley routes that follow waterways (drainage oriented routes) frequently encounter considerable curvature and the potential for floods and landslides. Routes along ridges are free of the stream hazards but may encounter slides and heavy curvature. Low local relief is desirable as it minimizes gradients and the requirement for the costly construction of cuts, tunnels, and fills. The patterns, profiles, and dimensions of the terrain affect the railroad's response and the necessity to construct a rail line through tunnels and bridges, on cuts and fills, around curves, and up and down grades. Subsequently and inexorably, the maintenance of way of that rail line will be permanently affected by the terrain.

This study provides the geographer with a method to integrate the effects of climate and terrain on maintenance of way into the total location analysis of a rail network. These methods would assist the location analyst in planning a rail network in a developing country, or, as will be discussed in the next section, in the relocation or abandonment of an existing network.

With some modification, the methods used in this study could be extended to the nation's highways with a system of

Highway Maintenance Zones developed to assist transportation planners. Of the 10 variables used in the formulation of the Railroad Maintenance Zones, only the sinuosity ratio and total curvature variables would require modification to appropriate highway design parameters. Highway maintenance managers could use the concept of maintenance zones to map their areas of responsibility and compare the zones with maintenance problem areas and/or highway maintenance costs.

A project for geographers using Geographic Information System (GIS) technology would be to map an entire region, state, or the United States in terms of maintenance zones along existing transportation networks. Major railroad companies, such as the Burlington Northern, CONRAIL, the Illinois Central, and the Union Pacific, provide extensive networks with standardized maintenance of way across other sections of the country. The 42,500-mile Interstate Highway System, with its relatively uniform engineering and maintenance standards, provides coverage throughout most of the country. Using GIS, geographers could "layer" the maintenance zones on the transportation networks to develop fully integrated maps for use by transportation planners.

A project with strategic military ramifications is the mapping of proposed alignments in terms of maintenance zones in the absence of existing rail networks. Under current strategic scenarios, military operations in northern Africa, the Middle East, and southwest Asia have received a great deal of attention. In these contingency areas, U.S. Army rail units would have to be employed to support the theater of operations. Railroads are considered the most important type of inland transportation because of the direct logistic support they provide to military operations. From the Military Geographic Information standpoint, the development of rail networks or the maintenance of existing networks is essential for extended military operations and receives the attention of personnel at the highest levels of command. Current doctrine, with its emphasis on the dispersal of units and the requirements for more and smaller rear-area installations also adds to the importance of maintaining rail networks. Railroads become more important in operational areas in which the trafficability of soils is low, and the highway/road systems are poor, but rail facilities are available. Frequently railroads assume a greater role in logistics contingency planning than highways, because of the terrain and climate as well as the operational objectives in the contingency area.[119] In any case, climate and terrain information incorporated in a GIS to produce railroad or highway maintenance zones could assist military logistics planners in selecting optimized routes for railroad as well as highway networks.

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[119] Department of the Army, *FM 55-20, Army Rail Transport Units and Operations* (Washington, D.C.: Government Printing Office, 1986), 1-2.

Maintenance Management Planning for Railroads

The application of this study to the railroad industry is twofold. First, rail companies could use the concepts of Railroad Maintenance Factors and Zones to evaluate and manage their existing networks. Second, this study highlights specific areas of difficult maintainability along a Norfolk Southern route that suggest future consideration for relocation. Similar studies on other routes would assist in their optimization of those routes, particularly in areas of greater climate and terrain variability.

Chapter I discussed the importance of maintenance of way to the railroad industry in terms of safety (derailments and hazardous cargo), train speeds (marketability and productivity), and smoothness of ride (loss and damage claims). The maintenance management of railroad networks is critical to the efficient operation of the company, particularly in this economic era of deregulation. This geographic study has provided a railroad company with detailed information on the location of maintenance problems and possible explanations for the problems in terms of the relationships of climate and terrain. The distribution of the RMZ's may suggest a reallocation of resources to prevent future maintenance problems. Detailed knowledge of specific segments of a route (RMZ) that are inherently difficult and expensive to maintain could assist a railroad company's efforts to abandon that segment of non-profitable track. In another scenario, this same rationale could be used to justify a rate increase, particularly for those railroads operating in areas of rugged terrain and extreme climatic variations. Railroad analysts considering mergers with other companies, especially companies operating in different environments, might consider using the model from this study to provide an insight into the potential maintenance problems and costs for that company.

"The terrain features that determined the geographical pattern of the railroad lines in the era of development, still exert their influences today."[120] In those days, the degree and length of curves were disregarded as rail lines following river valleys occasionally had as many curves as the course of the river, and the degree of curvature was a function of the path and meanders of the river. The route of the Norfolk Southern along the Tug Fork River is an example of most of the route's curvature being controlled by the character of the surrounding terrain. While tunnels were constructed when absolutely necessary to maintain grade and reduce curvature, the overriding consideration for the railroad in the 1890's was access to the coal fields and tipples.

With today's technologies, more direct routes along the Tug Fork River could be constructed through the spurs or

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[120] Lalor, "The Effect of Physiography on the Railroad Pattern of New England," 68.

"noses" in the adjacent valley walls to reduce curvature. Compared to the technologies of the 1890's and early 1900's, when most of the tunnels on this Norfolk Southern route were constructed, the use of explosives, power machinery, and engineering technologies to bore through bedrock suggest modern-day solutions to age-old problems. In Europe, there are many excellent examples of railroad tunnel construction including the 12.3-mile Simplon Tunnel through the Alps. The 7.8-mile New Cascade Tunnel in Washington and the 6.2-mile Moffat Tunnel in Colorado, both opened in 1929, are good examples of American tunnel engineering, although constructed over 60 years ago.

This study could assist Norfolk Southern engineering planners in considering some relocation possibilities. Certainly, the relocation of rail lines is an expensive proposition, but the long-term savings in reduced operating and maintenance costs should be considered. Even in the short term, the salvage value of the abandoned section of the line may offset to some extent the cost of the relocation construction, particularly if several miles are relocated. Tunnels are expensive, but if constructed properly and with adequate drainage, they will pay for themselves. During the author's "hy-rail" trips in the Pocahontas Division, the 7,107-foot long Elkhorn Tunnel, constructed in 1950, was maintained in excellent condition, primarily because it is concrete-lined and has concrete drainage channels.

From the research conducted in this study, the construction of tunnels to reduce curvature and associated costs could be considered at the following Mileposts: (1) N-334, a 3.5-mile tunnel through East River Mountain between Narrows, Virginia, and Wills, West Virginia, to eliminate the sliding and flooding problems at Glen Lyn (32) RSU as well as reduce the sinuosity ratio from 1.52 to 1.08 and the total curvature from 308° to 123°; (2) N-386, a .5-mile tunnel to eliminate a 12° curve between North Fork and Keystone and reduce the sinuosity ratio from 1.44 to 1.12 and the total curvature from 394° to 100° in the Elkhorn (36) RSU; (3) N-410.1, a 3-mile tunnel between Hensley and Wilmore to eliminate the consecutive series of five bridges and five tunnels near Roderfield as well as reduce the sinuosity ratio from 1.48 to 1.27 and the total curvature from 231° to 127° in the Iaeger (39) RSU; and (4) N-433, a 1-mile tunnel to eliminate a meander bend at Ainwick and reduce the sinuosity ratio from 1.68 to 1.37 and the total curvature from 266° to 204° in the Wharncliffe (41) RSU. A recomputation of the RMF's with the proposed tunnels for the four RSU's mentioned above would change, in each case, the Railroad Maintenance Class (RMC) from Very High to High.

A second consideration from this study would be to relocate the route out of Goose Creek between Leesville and

Stone Mountain, Mileposts V-205 to V-218. A suggested alignment would locate the route on the interfluve next to state highway 43, then turn northwest at Route 731 to pass 1.2 miles north of Huddleston, and then to proceed west to Stone Mountain. Although this route would require some additional bridging, it would remove the route from the flood and slide prone area along Goose Creek near Huddleston. With the elimination of the flood potential along Goose Creek, the RMC for the Huddleston RSU would change from High to Medium.

Again, the Norfolk Southern is living with a roadbed that was designed and constructed without the benefit of modern geotechnical analysis. This study suggests new avenues for long-term cost reduction and rail system efficiency.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

The narrow ridges, steep mountain escarpments, and dissected plateaus of the Appalachians were physical barriers to westward expansion during the development of the United States. The few river gaps through the Blue Ridge and Allegheny Front focused the early railway networks, such as the Norfolk and Western Railway, as they worked westward from the Atlantic coast. In the case of the Norfolk Southern route between Norfolk and Portsmouth, its alignment also reflected the economic desire to access and transport coal from the coal-bearing mountains of West Virginia, southwestern Virginia, and eastern Kentucky. The decisions as to the location of the rail line, made over 100 years ago in the case of the former Norfolk and Western Railway trackage, continue to affect the operation and maintenance of the Norfolk Southern route between Norfolk and Portsmouth.

While the climatic conditions along the route had to be accepted, the specific alignment was clearly influenced by the interaction of climate and terrain. It was usually more economical to develop a rail line with a reduced gradient and longer distance than to have trains ascending steep grades on the uplands. To avoid terrain obstructions, rail lines followed drainageways, which reduced overall distance but increased curvature and the potential for problems with rock slides and floods. The tributaries of the main river valleys, such as Goose Creek and the East River, provided a means for crossing from one valley to another by reasonable grades. The horizontal pattern of ridge crests and valleys strongly influenced the directness and amount of curvature of the route, while longitudinal and transverse profiles of divides and uplands influenced the location of crossing points of mountains and ridges and the feasibility of using interfluve approaches. Drainage-oriented routes were seen as a solution for breaching the terrain barrier imposed by the Appalachians, but these alignments also imposed terrain-related problems that continue to affect the maintenance of way along the study route.

While the study route takes advantage of interfluves for 150 miles between Norfolk and Abilene, the route descends from Abilene to the Roanoke River Valley where, for most of the remainder of the route, the track follows drainageways (New, East, and Bluestone rivers, Mill and Elkhorn creeks, and the Tug Fork, Big Sandy, and Ohio rivers). The major exception is the ascent of Christiansburg Mountain between the Roanoke and New River basins. In the Appalachian Highlands, the decision to locate the route in the narrow, winding valley of the Tug Fork was necessitated by the fact that the ridge crests in this area were too narrow and discontinuous to allow for the construction of a more advantageous rail line. As previously discussed, accessibility to the coal mines and tipples was a paramount concern to the Norfolk and Western Railway and also influenced the alignment.

Does the route represent the most direct and efficient route for the Norfolk Southern? Yes, given the technology of the period when it was built, the economic demands of the coal industry, which it was built to serve, and the climate and terrain of the area. As engineering and railroad technology improved during the 20th Century, why did not the Norfolk and Western consider any major relocations to improve operating and maintenance of way costs? Gillenwater (1972) suggests that the development of coal mines and their associated settlements were influenced by: (1) slope and elevation of coal seams, (2) availability of coal leases, (3) improvements in coal mining techniques, and (4) location of the railroad.[121] Relocations of the rail line were certainly limited in extent by the existence of the settlement pattern created along the Norfolk and Western route. Relocation was generally limited to local improvements; the last major relocation occurred near Williamson in the 1940's.

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[121] Mack H. Gillenwater, "Cultural and Historical Geography of Mining Settlements in the Pocahontas Coal Field of Southern West Virginia" (Ph.D. diss., University of Tennessee, 1972), 28-30.

This study has provided a geographical analysis of the maintenance problem areas along the Norfolk Southern route between Norfolk and Portsmouth. Given the economic realities of today in terms of the coal and railroad industries, the study does not suggest a major route relocation. It does focus on problem areas that will continue to generate high maintenance costs because of the existing relationships to the surrounding terrain and local climate patterns. To preclude continually paying for remedial and usually short-term maintenance solutions, the study does suggest several problem areas that should be investigated by transportation planners for possible relocation. It is understood that Norfolk Southern is considering abandoning a 110-mile section of track near Connelsville, Ohio, because of frequent problems with rockslides and unstable subgrade. While relocation rather than abandonment is suggested for sections of this study route, the willingness of Norfolk Southern to consider environmental as well as economic factors on track alignments illustrates the need for further geographic analysis in the railroad industry.

This study also suggests further study in a new field of transport microclimatology. Very little work has been done into the climatology of transportation systems other than in the area of aviation. The permanent way of railroads, in the form of track and roadbed, consists of different components, each with varying thermal properties. These properties, combined with the effects of wind, precipitation, and insolation, create microclimatic conditions along the roadway that affect maintenance of way.

Using the Norfolk Southern rail line between Norfolk and Portsmouth, this study has attempted to illustrate a geography of railroad maintenance of way. Detailed analysis of the distribution of maintenance problems along the study route suggests relationships between the environmental factors of climate and terrain and maintenance of way. The methodology presented in the study utilized 54, 10 track-mile Railroad Study Units, and 10 climate and terrain variables to develop Railroad Maintenance Factors for each RSU. Of these variables, the ones associated with terrain were found to be more important than the climatic variables. These RSU's were further grouped into Railroad Maintenance Zones and projected along the 540 miles of the study route. These maintenance zones were shown to parallel the classes of land-surface form as described by Hammond and to reflect the variations of climate and terrain along the study route. An understanding of the relationships of climate and terrain to maintenance of way can assist transportation planners in developing new routes or relocating existing routes to reduce long-term maintenance costs and to improve system efficiency. Extensions of the methods used in this study to other modes of ground transportation and to other regions would enhance the geographical understanding of the relationships between land-surface systems and ground transportation networks. Military applications of the study to military logistics contingency planning are also presented. Complete analysis of existing railroad networks may provide sufficient data to map regions on the basis of railroad maintainability; this effort could be facilitated with the use of today's Geographic Information Systems and digital terrain models.

This study suggests that railroad maintenance problems are strongly keyed to environmental factors reflecting the railroad's location in areas of varying terrain and climate. Transportation planners should consider these environmental factors, not only for the initial route location, but also for the subsequent, long-term maintenance costs.

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APPENDIX

TABLE 11

GEOLOGY AND SOIL ANALYSIS OF RAILROAD STUDY UNITS (RSU'S)

Segment	RSU No.	Mileposts	Brief Geology and Soil Description
Yadkin	1	N-8.0/N-18.2	Coastal plain sediments, Great Dismal Swamp, inverted topography, unconsolidated gravels, sands, clays, and marls. Quaternary sediments.
Suffolk	2	N-18.2/N-28.0	Coastal plain sediments, eastern half of segment across Great Dismal Swamp. Organic material at subsurface layer. Tertiary sediments at Suffolk.
Windsor	3	N-28.0/N-38.1	Coastal plain sediments, broad upland and swamps. Poorly drained, sandy, clay-loam soils. On broad, flat uplands.
Ivor	4	N-38.1/N-48.5	Mid coastal plain sediments, swampy alluvial flats along Blackwater River. Sandy, clay-loam subsoil.
Wakefield	5	N-48.5/N-58.4	Mid coastal plain sediments of unconsolidated gravels, sands, clays, and marls.
Waverly	6	N-58.4/N-68.5	Sand, gravel, and clay with loam at the surface. Ascends ancient terrace. Formed in fluvial and marine sediments.
New Bohemia	7	N-68.5/P-0.6	Upper coastal plain,Tertiary sands and gravels. Sandy loam.
SW Petersburg	8	P-0.6/N-90.2	Inland boundary of coastal plain, Tertiary sediments over Petersburg granite. Western end of segment at Piedmont boundary. Clay-loam soil.
Church Road	9	N-90.2/N-100.4	Piedmont lowland underlain by light-colored granite or granite gneiss at depth; covered by blanket of sapprolite. Gentle, rolling topography. Clay-loam soil, sandy.
Hebron	10	N-100.4/N-110.0	Piedmont lowland; granites and gneiss and other metamorphics, structural drainage control, clayey-loam soil, sandy loam.
Blackstone	11	N-110.0/N-120.0	Piedmont crystalline rocks, tracks follow interfluve. Granite and granite gneiss. Clay-loam soil.
Crewe	12	N-120.0/N-130.2	Piedmont granites and gneiss or pegmatite. Sandy and clay-loam soils.
Burkeville	13	N-130.2/B-7.0	Well-dissected upland, ridges composed of granite, gneiss, schists, and pegmatite. Sandy-loam soils and clay loam.

TABLE 11 (continued)

Segment	RSU No.	Mileposts	Brief Geology and Soil Description
Virso	14	B-7.0/B-17.0	Piedmont; area underlain by mica schists, more than granite and gneiss.
Abilene	15	B-17.0/V-147.5	Quartz-feldspar gneiss and schists of the Piedmont. Clayey subsoil.
Phenix	16	V-147.5/V-157.5	Rolling to hilly terrain, dissected by many streams, loamy-clay soil with mica flakes; still in Piedmont upland.
Aspen	17	V-157.5/V-167.8	Piedmont; igneous and metamorphic granites, gneiss, schist. Crystalline bedrock has weathered to clay and red hematite.
Brookneal	18	V-167.8/V-178.1	Piedmont, well-dissected, region of complex igneous or metamorphic rocks; granite, greenstone, gneiss, quartzite, schist; some sedimentary sandstone and shale. Along Roanoke River.
Long Island	19	V-178.1/V-188.2	Piedmont upland; soils are clayey, formed from weathered Triassic sandstone and shale; Triassic Danville Basin. Crosses Chatam Fault. Along Roanoke River.
Altavista	20	V-188.2/V-198.7	Piedmont upland; clayey subsoils from weathered greenstone, horne-blend, gneiss, and diorite, some mica schist. Over Smith River Allochthon, with metasedimentary rocks and igneous intrusions. Along Roanoke River.
Leesville	21	V-198.7/V-209.0	Piedmont upland; clayey subsoil, on narrow flood plains. From weathered granite gneiss, quartz schist, and quartzite. Over Smith River Allochthon. Along Roanoke River.
Huddleston	22	V-209.0/V-219.3	Piedmont upland; cross Bowens Creek Fault near Huddleston; schists, gneisses, sandstones, some marble. Along Goose Creek.
Moneta	23	V-219.3/V-229.5	Enter Blue Ridge province; Overlies Grenville granites and gneisses of Blue Ridge Thrust Sheet.
Hardy	24	V-229.5/V-239.7	Blue Ridge (older Appalachians) of pre-Cambrian rocks, highly meta-morphosed; gneiss and granite. Along Roanoke River on west half of segment.
Salem	25	V-246.8/V-257.0	Ridge and Valley province; clayey or loamy residuum or alluvium of limestone, shale, sandstone, or granite on flood plains. Paleozoic limestones. Along Roanoke River.

TABLE 11 (continued)

Segment	RSU No.	Mileposts	Brief Geology and Soil Description
Lafayette	26	V-257.0/V-267.3	Ridge and Valley; silt loam soil on flood plains from recent alluvium of limestone, shale, and sandstone in limestone valleys. On North Fork of Roanoke River.
Ellett	27	V-267.3/V-277.7	Approach to Christiansburg Mt., Atlantic-Gulf divide. Soils from residuum of limestone interbedded with siltstone and shale. Segment ends in Merrimac Tunnel. Crosses Salem Fault at Yellow Sulphur.
Whitethorne	28	V-277.7/V-288.1	Ridge and Valley, Pulaski Thrust Sheet in Blacksburg Syncline basin. Price formation of shale, sandstone, and clay; soils are silty clay loam. Along New River.
Eggleston	29	V-288.1/V-298.3	New River Valley, loamy and clayey subsoil formed on old alluvium on stream terraces; from shale and sandstone.
Pembroke	30	V-298.3/V-308.6	New River Valley; clayey subsoil on old alluvial deposits from igneous and sedimentary materials. Limestone/shale uplands; ridges are sandstone and shale.
Narrows	31	V-308.6/N-334.6	Silt loam soil weathered from dolomite and limestone, clayey subsoil; at New River gap through Peters/E. River Mt., steep slopes susceptible to rockfalls and slides. Tracks cross the Narrows Fault at Narrows.
Glen Lyn	32	N-334.6/N-344.8	Clay loam subsoil on alluvial deposits. Through narrows of New River, Clinch sandstone on ridges dipping to river. Crosses St. Clair Fault south of Rich Creek; tracks follow East River at Hurricane Ridge Syncline, Ridge and Valley boundary.
Ingleside	33	N-344.8/N-355.3	Along East River; Ridge and Valley/Appalachian Plateau boundaries; silt loam soil formed in lime-influenced alluvial materials; parallels the St. Clair Fault, on limestones.
Bluefield	34	N-355.3/N-365.5	Along East River, loamy, silt loam soil on flood plains subject to flooding. Formed in alluvial material washed from lime-influenced soils on uplands. On limestone and limey shale.

TABLE 11 (continued)

Segment	RSU No.	Mileposts	Brief Geology and Soil Description
Bluestone	35	N-365.5/N-375.7	Shaly, silt loam soil, on hillsides and benches from shale, siltstone, and some sandstone. Crosses Hurricane Ridge Syncline into Appalachian Plateau. Along Bluestone River.
Elkhorn	36	N-375.7/N-387.1	Loam and silt loam soils weathered from sandstone, siltstone, and some shale. Geology is Pocahontas formation of 50% sandstone, some shale, siltstone, and coal. Along Elkhorn Creek.
Kimball	37	N-387.1/N-398.5	Sandstone, shale, siltstone, and coal. Mississippian. Along Elkhorn Creek. Loam, silt loam soil; deep, well-drained.
Davy	38	N-398.5/N-411.1	New River Formation; predominantly sandstone with some shale, siltstone, and coal. Pennsylvanian. Along Tug Fork River. Sandy, loam soil.
Iaeger	39	N-411.1/N-423.5	Sandstone with some shale, siltstone, and coal. Along Tug Fork River. Stony loam; weathered from sandstone and colluvial material.
Panther	40	N-423.5/N-433.0	Sandstone with some shale, siltstone, and coal. Along Tug Fork River. Channery loam, weathered from colluvial material derived from sandstone, silt, and shale at base of slopes, on benches.
Wharncliffe	41	N-433.8/N-444.5	Kanawha formation; 50% sandstone, shale, siltstone, and coal beds. Along Tug Fork River.
Vulcan	42	N-444.5/N-455.0	Predominantly sandstone on beds of shale, siltstone, and coal. Along Tug Fork River. Channery, sandy loam soils.
Matewan	43	N-455.0/N-465.3	Sandstone with interbedded shale, siltstone, and coal. Along Tug Fork River. Stony, sandy loam soils.
Williamson	44	N-465.3/N-476.5	Sandstone with interbedded shale, siltstone, and coal of the Kanawha formation. Along Tug Fork River. Sandy loam with fragments.
Naugatuck	45	N-476.5/NA-2.3	Appalachian Plateau, still in sandstone with beds of shale, siltstone, and coal, Kanawha formation. Along Tug Fork River. Sandy loam soil.
Kermit	46	NA-2.3/NA-12.8	Sandstone, shale, siltstone, and coal. Tracks cross Warfield Fault south of Kermit. Along Tug Fork River. Sandy loam soil.

TABLE 11 (continued)

Segment	RSU No.	Mileposts	Brief Geology and Soil Description
Webb	47	NA-12.8/NA-22.3	Sandstone, shale, siltstone, and coal along the Tug Fork River. Stony, sandy loam soil.
Glenhayes	48	NA-22.3/NA-32.3	Sandstone, shale, siltstone, coal of Kanawha formation; along Tug Fork River. Sandy loam soil.
Fort Gay	49	NA-32.3/NA-42.7	On Quaternary alluvium of sand, gravel, silt, and clay; Tug Fork joins Big Sandy River at Fort Gay. Silt loam soil.
Cyrus	50	NA-42.7/NA-52.0	Allegheny formation on cyclic sequences of sandstone, siltstone, shale, limestone, and coal. Along Big Sandy River. Silty loam soils on terraces and flood plains.
Kenova	51	NA-52.0/N-572.1	Silt loam soil on terraces; high water table (perched at 1 to 3 ft); subject to flooding on rare occasions. Formed on alluvium. On Quaternary alluvium of sand, gravel, silt, and clay.
Ironton	52	N-572.1/N-582.6	Silt loam soil on flood plains formed in alluvium, occasionally flooded. Alluvium consists of shale, sandstone, and conglomerate material.
Haverhill	53	N-582.6/N-592.8	Silt loam soil on terraces; formed in old alluvium of shale, sandstone, and conglomerate.
Sciotoville	54	N-592.8/N-603.1	Silt loam soil on terraces along streams formed on old alluvium of shale, sandstone, and conglomerate.

VITA

Thomas Brock Maertens, Jr. [redacted], [redacted]. As the son of a career military officer, he attended schools in many different areas of the United States and overseas. In 1966, he graduated from Robert E. Lee High School in Springfield, Virginia. In July of that year, he entered the United States Military Academy at West Point, New York, where he graduated with a Bachelor of Science degree in June 1970.

From 1970 to 1978, he served as a commissioned officer in the U.S. Army with assignments in North Carolina, the Republic of South Vietnam, Kentucky, Virginia, and Alabama. In 1976, while stationed at the Army's Transportation School at Fort Eustis, Virginia, he received a Master of Science degree in Transportation Management from the Florida Institute of Technology.

In September 1978, he entered the Graduate School of the University of Tennessee at Knoxville. He was awarded a Master of Science degree in geography in June 1980. After graduation, he served as an Assistant Professor of Geography at the United States Military Academy until June 1983.

After aviation assignments at Fort Eustis, Virginia, and Mannheim and Heidelberg, West Germany, Lieutenant Colonel Maertens returned to the Graduate School of the University of Tennessee at Knoxville in January 1988. The Doctor of Philosophy degree with a major in geography was conferred in August 1990. After graduation, he will be assigned as an Associate Professor in the Department of Geography and Environmental Engineering at the United States Military Academy at West Point.

He is married to the former Karen Lee Kellar of Cocoa Beach, Florida. They have one child, McKenna Elise.